

**AFRL-IF-RS-TR-2004-58**  
**Final Technical Report**  
**March 2004**



## **WIRELESS INTEGRATED NETWORK SENSORS (WINS) NEXT GENERATION**

**Sensoria**

**Sponsored by**  
**Defense Advanced Research Projects Agency**  
**DARPA Order No. H578**

*APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.*

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the U.S. Government.

**AIR FORCE RESEARCH LABORATORY  
INFORMATION DIRECTORATE  
ROME RESEARCH SITE  
ROME, NEW YORK**

## **STINFO FINAL REPORT**

This report has been reviewed by the Air Force Research Laboratory, Information Directorate, Public Affairs Office (IFOIPA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

AFRL-IF-RS-TR-2004-58 has been reviewed and is approved for publication.

APPROVED:                            /s/  
RICHARD C. BUTLER  
Project Engineer

FOR THE DIRECTOR:                            /s/  
WARREN H. DEBANY, JR.  
Technical Advisor  
Information Grid Division  
Information Directorate

# REPORT DOCUMENTATION PAGE

*Form Approved  
OMB No. 074-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	MARCH 2004	FINAL	Aug 99 – Feb 03
4. TITLE AND SUBTITLE			5. FUNDING NUMBERS
WIRELESS INTEGRATED NETWORK SENSORS (WINS) NEXT GENERATION			C - F30602-99-C-0171 PE - 62302E PR - H578 TA - 16 WU - 01
6. AUTHOR(S) William Merrill William Kaiser			8. PERFORMING ORGANIZATION REPORT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Sensoria Corporation 200 Corporate Pointe, Suite 100 Culver City CA 90230			N/A
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)  Defense Advanced Research Projects Agency 3701 North Fairfax Drive Arlington VA 22203-1714			10. SPONSORING / MONITORING AGENCY REPORT NUMBER  AFRL-IF-RS-TR-2004-58
11. SUPPLEMENTARY NOTES  DARPA Program Manager: Sri Kumar/IPTO/(703) 696-0174 AFRL Project Engineer: Richard C. Butler/IFGA/(315) 330-1888      Richard.Butler@rl.af.mil			
12a. DISTRIBUTION / AVAILABILITY STATEMENT  <i>APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.</i>			12b. DISTRIBUTION CODE
13. ABSTRACT ( <i>Maximum 200 Words</i> )  During the WINS NG program, three generations of networked embedded sensor development systems were created, with over 180 of these systems provided to both the SensIT and NRL SRSS development communities. In addition to the supply of development systems, throughout this contract, support was provided to multiple teams of developers investigating various problems in collaborative signal processing, autonomous networking, and distributed operations for wireless networked sensor systems. Multiple types of sensor systems were developed and provided including capabilities for acoustic, seismic, passive infrared detection, and visual imaging. These systems were demonstrated as multiple tests and experiments by multiple groups Sensoria was supporting for each of the three years of this program.			
14. SUBJECT TERMS  Distributed Sensor Networks, Collaborative Processing, Distributed Micro Sensors, Sensoria Nodes, SenSoft v 1.0, WINS Imager, SITEX Demonstrations, SensIT, Sensors			15. NUMBER OF PAGES 65
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT  UNCLASSIFIED		18. SECURITY CLASSIFICATION OF THIS PAGE  UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT  UNCLASSIFIED
20. LIMITATION OF ABSTRACT  UL			

## TABLE OF CONTENTS

<b>1</b>	<b>SUMMARY OF THE RESEARCH.....</b>	<b>1</b>
<b>2</b>	<b>INTRODUCTION TO THE WINS NEXT GENERATION PROGRAM .....</b>	<b>1</b>
2.1	WINS NEXT GENERATION: APPROACH .....	2
<b>3</b>	<b>WINS NG 1.0 SENSOR DEVELOPMENT PLATFORM.....</b>	<b>3</b>
3.1	WINS NG 1.0 PLATFORM COMPONENTS .....	5
3.1.1	<i>WINS NG 1.0 Sensors .....</i>	5
3.1.2	<i>WINS NG Preprocessor .....</i>	7
3.1.3	<i>WINS NG Processor .....</i>	8
3.1.4	<i>WINS NG RF Modem.....</i>	11
3.1.5	<i>WINS NG Package.....</i>	13
3.2	WINS NG 1.0 SOFTWARE API .....	13
3.2.1	<i>WINS NG Framework Application: WINS NG 1.0 API.....</i>	14
3.3	WINS NG 1.0 NODE POWER DISSIPATION SPECIFICATIONS .....	14
3.4	WINS NG 1.0 DEPLOYMENT AT SITEX00 .....	15
3.5	WINS IMAGER .....	18
3.5.1	<i>Imager Architecture .....</i>	18
3.5.2	<i>Imager Software.....</i>	20
3.5.3	<i>Imager Network .....</i>	20
3.5.4	<i>WINS Imager Specifications .....</i>	21
3.5.5	<i>Use of the WINS Imager at SITEX01 .....</i>	22
3.6	WINS NG 1.0 SUMMARY .....	24
<b>4</b>	<b>WINS NG 2.0 SENSOR DEVELOPMENT PLATFORM.....</b>	<b>24</b>
4.1	ADAPTIVE NODE PLATFORM.....	24
4.2	ADAPTIVE ANALOG SENSING AND SIGNAL PROCESSING PLATFORM .....	26
4.3	ADAPTIVE RF NETWORK .....	28
4.3.1	<i>WINS NG 2.0 Networking .....</i>	28
4.3.2	<i>Automatic Cluster Formation .....</i>	31
4.3.3	<i>The Sensoria Visualization Tool used with WINS NG 2.0.....</i>	33
4.4	802.11B WIRELESS NETWORK INTERFACE SETUP FOR WINS NG 2.0 NODES ...	34
4.5	WINS NG 2.0 SOFTWARE DEVELOPMENT ENVIRONMENT .....	34
4.6	POWER SPECIFICATIONS.....	36
4.7	GPS TECHNICAL SPECIFICATIONS.....	37
4.8	WINS IMAGER 2.0 .....	37
4.8.1	<i>Improvements over the Prior Sensoria WINS Imager .....</i>	38
4.8.2	<i>The WINS 2.0 Imager Architecture.....</i>	39
4.8.3	<i>Steel Knight WINS Deployment Status Report.....</i>	40
4.9	ADDITIONAL WINS NG 2.0 DEPLOYMENTS .....	51
<b>5</b>	<b>SENSORIA NETWORKING FOR NRL SRSS.....</b>	<b>52</b>
5.1	INITIAL PROTOTYPE FOR IP CONNECTIVITY OVER ARBITRARY WIRELESS INTERFACES .....	53

<b>6</b>	<b>WINS NG 3.0 RESEARCH.....</b>	<b>54</b>
<b>7</b>	<b>CONCLUDING REMARKS ON THE WINS NG PROGRAM .....</b>	<b>55</b>
7.1	SENSIT PROGRAM.....	55
7.2	NRL SRSS .....	55
7.3	LIST OF PUBLICATIONS AND INVENTIONS SUPPORTED BY THE CONTRACT.....	55

## List of Figures

Figure 1. The WINS NG network architecture includes WINS NG Nodes, Gateways, Server and Web access components.....	4
Figure 2. The WINS NG Node Architecture. This architecture has been developed to provide support for both real-time, constantly vigilant signal processing and support for software development in non-real time platforms.....	5
Figure 3. The WINS NG Preprocessor. This includes the Sensor Interface Processor (shown in Figure 4). The Preprocessor is a low power component with sleep control capability.....	8
Figure 4. The <i>Sensor Interface Processor</i> including a static CMOS microprocessor and sampling system. The sampling system includes a set of programmable, switched capacitor, analog anti-aliasing input filters.....	8
Figure 5. The WINS NG Power Supply. The WINS NG Power Supply is a low power system intended to support a multiplicity of sensors and interfaces with both low average power, and high peak power performance. ....	8
Figure 6. WINS NG Processor throughput test for a 64-tap FIR filter.....	9
Figure 7. WINS NG Processor throughput test for a 128-tap FIR filter.....	10
Figure 8. WINS NG Processor throughput test for a 512-tap FIR filter.....	10
Figure 9. WINS NG Data Frame. Unicast and Broadcast addressing are supported.....	13
Figure 10. The WINS NG environmentally resistant package. Sensors are placed external to this package for optimal performance. ....	13
Figure 11. The WINS NG API is shown including low-level functions for access to physical world interfaces and support for the full SensIT Applications.....	14
Figure 12. WINS NG 1.0 Power dissipation by subsystem.....	14
Figure 13. View from the command area of the SITEX test site at the MCAGCC, Palms CA.....	15
Figure 14. WINS NG 1.0 node as setup and left for 2 weeks during SITEX00.....	16
Figure 15. Example data collected from a seismic (#1), acoustic (#2), and passive infrared (#3) sensor on a WINS NG 1.0 node at SITEX00.....	16
Figure 16. Display of data collected on WINS NG 1.0 nodes as an AAV (shown in the inset) passed. Sensor detections are shown with green circles and colors coordinated to the sensor detection type, with node locations shown in white. ....	17
Figure 17. Display of Infrared detections by WINS NG 1.0 nodes as a column of infantry (shown in the time-stamped picture) pass.....	17
Figure 18. WINS Imager Setup with passive infrared trigger. ....	18
Figure 19. Imager triggering options. All are interchangeable.....	19
Figure 20. WINS Imager stand-alone Laptop interface.....	20
Figure 21. WINS Imager Base Station User Interface. This base station was located at the Base Camp Promontory shown below. ....	23
Figure 22. SITEX00 demonstration area, indicating the deployment of the WINS Imager and the Base Camp Promontory sites. ....	23
Figure 23. Typical images obtained with the WINS Imager operating at the remote site in the SITEX exercise. ....	24
Figure 24. Block diagram of the WINS NG 2.0 platform .....	25

Figure 25. (a) WINS NG 2.0 Processor Core and (b) Sensor Interface System.....	25
Figure 26. Illustration of the Base and Remote building block for the network architecture.....	29
Figure 27. Illustration of dual node networks showing all one-hop paths between bases and remotes. ....	29
Figure 28. Illustration of three overlapping networks. Node numbers are shown in black with each associated RF modem labeled with letters. ....	31
Figure 29. Screen capture of the Sensoria visualization GUI.....	33
Figure 30. WINS 2.0 Imager atop a battery pack. ....	38
Figure 31. WINS 2.0 Imager architecture.....	40
Figure 32. Steel Knight deployment aerial view .....	41
Figure 33. Steel Knight network architecture .....	41
Figure 34. WINS Imager 2.0 Current Data Page.....	42
Figure 35. Imager 1 and 2 deployment at a berm near road. The Imager locations are indicated by the black rectangles and the Imager viewing angles are indicated by the arrows.....	43
Figure 36. View of the WINS Imager 2.0 History Page.....	43
Figure 37. Alarm Page pop-up window graphic indicating alarm state for Imager 1. ....	44
Figure 38. Alarm Page pop-up window graphic indicating alarm state for Imager 2. ....	44
Figure 39. View of COC area from OP Kumar .....	45
Figure 40. View from OP Kumar towards Sensor Site. Dust from vehicle passage is observed on the roads.....	46
Figure 41. Imager 1 captures HMMWV with automatic weapon in time sequence image pair. Note that image sequence offers two viewing angles and backgrounds, rendering the weapon more visible in the second image. (From 6 Dec 2001 image database.) .....	47
Figure 42. Imager 2 captures HMMWV with automatic weapon (as shown in Figure 41) Note that this provides another set of angular views and backgrounds. (From 6 Dec 2001 image database.).....	47
Figure 43. Imager 1 captures AAV. (From 6 Dec 2001 image database.) .....	48
Figure 44. Imager 2 captures AAV of Figure 43. (From 6 Dec 2001 image database.)..	48
Figure 45. Imager 1 sequence showing HMMWV with automatic weapon. (From 6 Dec 2001 image database.)......	49
Figure 46. Imager 2 sequence showing HMMWV with automatic weapon. (From 6 Dec 2001 image database.).....	49
Figure 47. Imager 2 and Imager 1 capture an LAV passage at 13:31 on 5 Dec. ....	49
Figure 48. M925 5-Ton in first of an Imager 1 sequence. (From 6 Dec 2001 image database.) .....	50
Figure 49. M925 5-Ton in second of an Imager 1 sequence – note vehicle is towing howitzer.....	50
Figure 50. M925 5-Ton in third of an Imager 1 sequence – note view of howitzer.....	51
Figure 51. WINS NG 2.0 node deployed at SITEX02. The large pole with caution tape was used to mark the location of the node to prevent it being run over. ....	51
Figure 52. Node layout, aerial map, and overview of the SITEX02 Experiment using 70+ WINS NG 2.0 nodes. ....	52

Figure 53. The layout of the preliminary driver architecture for universal wireless IP networking .....	53
Figure 54. Example of a system module stack .....	54
Figure 55. Sensoria next-generation WINS 3.0 embedded system modules.....	55

## List of Tables

Table 1: Summary of WINS NG 1.0 Sensors.....	6
Table 2: WINS NG 1.0 sensor interface specifications.....	7
Table 3: CCD Solid-state Image Pickup Element.....	21
Table 4: Remote Camera Power Specifications.....	21
Table 5: WINS Imager operating environment .....	22
Table 6: Timing Specifications.....	22
Table 7: WINS Imager General Specifications .....	22
Table 8: Processor specifications for the WINS NG 2.0 node. ....	26
Table 9: WINS NG 2.0 analog-sampling specifications.....	27
Table 10: WINS NG 2.0 adaptive analog section specifications.....	27
Table 11: WINS NG 2.0 specification for each of the two integrated RF modems. ....	28
Table 12: WINS NG 2.0 autonomous clustering options .....	32
Table 13: Operational lifetime of the WINS NG 2.0 nodes using its supplied battery. ...	37
Table 14: Specifications for the GPS system included with the WINS NG 2.0 nodes....	37
Table 15: WINS 2.0 Imager specifications.....	39

## **1 Summary of the Research**

Wireless Integrated Network Sensors (WINS) technology is a complete system of autonomous sensors, actuators, and processors linked by self-assembled wireless networks. WINS networks of sensors and controls form the bridge between the global Internet and the physical world. WINS nodes are compact, low power devices that may be rapidly deployed or installed at low cost. WINS are the first entry into a future of widely distributed Internetworked, wireless, embedded processors, sensors, and controls for security and other applications. WINS demonstrations have shown that defense systems will be fundamentally changed by low cost devices which are deeply and widely distributed in environments and integrated into assets for continuous, global monitoring and control for battlefield surveillance, security, environmental status, and condition based maintenance. There is now a confirmed set of WINS applications within the Department of Defense for battlefield surveillance and condition based maintenance on land, sea, and air vehicles. In addition, through the development at *Sensoria Corporation*, WINS networks are now Internet accessible, enabling global, remote, reconfigurable monitoring, control, and security.

Within the WINS NG program, Sensoria Corporation provided to both the Sensor Information Technology (SensIT) DARPA IXO coordinated development group, and to the Naval Research Laboratory SRSS Network research program, WINS development platforms, development support, and supporting research on improved WINS systems. This research included three generations of sensor development systems providing capabilities for both basic research on WINS systems, and for field deployment during real world experiments.

## **2 Introduction to the WINS Next Generation Program**

The deployment of WINS in the primary defense applications for battlefield, perimeter, and base security, as well as condition based maintenance environments, requires a low cost, scalable, self-installing architecture. The full advantage of WINS requires that these devices be densely distributed in the environment. This ensures that WINS sensing elements are located in relative proximity to potential threats and that multiple nodes may simultaneously be brought to bear on threat detection and assessment. This dense distribution, when combined with proper networking, enables multihop, short-range communication between nodes. This drastically reduces the most important WINS power demand, communication operating power. Additional innovations in WINS include devices that are continuously vigilant, sensing and processing all sensor data for the purpose of detecting the presence of a threat. The WINS nodes communicate only network management status (and synchronization) information except in the event of threat detection. In this event, the WINS network carries only threat event codes (pointers corresponding to codebook entries for identified threat signals), efficiently communicating the presence and nature of a threat. In the event that a threat is detected, but not identified, larger datasets must be migrated to a remote user. The scalability of this WINS network depends on powerful local computation capability, adaptation to the environment, remote reconfigurability, and communication security. These capabilities are being provided in this program by technologies and innovations in WINS Internetworking by *Sensoria Corporation*. In addition, a new WINS architecture supporting the required rapid delivery has been supplied as a powerful development platform to the DARPA SensIT research community, and to the NRL SRSS program.

The DARPA SensIT program leads the mission to develop the Information Technology required for deeply distributed, networked, inexpensive and pervasive platforms. These combine multiple, reprogrammable general-purpose processors, and wireless communication systems. The SensIT community includes the leaders in fields ranging from the development of diffusion protocols for

multi-hop routing through tactical sensor signal processing. A powerful WINS platform is required for the development of SensIT software systems.

The NRL SRSS program extends on the work done in the SensIT community to further investigate networking solutions appropriate for WINS systems, as well as considering additional radio interfaces via building on the WINS NG development systems.

Sensoria Corporation has developed multiple generations of a new WINS architecture, WINS Next Generation (WINS NG), to address the most important WINS defense applications that are now emerging. The WINS NG architecture includes WINS nodes operating as sensor and control devices, WINS nodes operating as network gateways, WINS server functions, and WINS Internet applications. The WINS NG platform, distributed to the SensIT community, permits the development of self-organizing networks robust multi-hop routing methods, network-enabled data correlation, and language interfaces for querying and tasking. The WINS NG platform is also being exploited by Sensoria Corporation (formerly known as Sensor.com) to develop new network, signal processing, and event recognition methods along with adaptive and reconfigurable sensing and communication systems, within their WINS NG program.

## **2.1 WINS Next Generation: Approach**

The WINS NG program provides an advance in tactical, distributed sensor technology. In addition, the WINS NG platforms provides a development opportunity for the SensIT and NRL SRSS Communities by supporting their requests and needs through multiple generations of the WINS NG development platforms.

The WINS NG program has supplied the multiple WINS NG platforms to the SensIT and NRL SRSS communities. WINS NG combines high performance sensing, actuator control, frequency-hopped spread spectrum communication and GPS location capability. The WINS NG multiprocessor computing platform provides a micro-power, constantly vigilant real world interface, as well as a 32-bit platform for power computation. Software APIs provide access to sensing, signal processing, communication, networking, and platform management for each processor.

The WINS architecture design addresses the constraints on robust operation, dense and deep distribution, interoperability with conventional networks, operating power, scalability, and cost. Robust operation and dense, deep distribution benefit from a multihop architecture where the naturally occurring short range links between nodes is exploited to provide multiple pathways for node-to-node, node-to-Gateway, and Gateway-to-network communication. WINS Gateways provide support for the WINS network and access between conventional network physical layers and their protocols and the WINS physical layer and its low power protocols.

Over the course of the WINS NG contract, Sensoria Corporation has researched, developed, and supplied multiple versions of the WINS NG networked sensor development platform, to enable the wider research community. Over the course of this effort, three versions of the WINS NG platform have been developed, with over 180 of the 1.0 and 2.0 platforms provided to the SensIT community, including a variety of sensing interfaces, including imaging. This technical report provides a summary of the research conducted by Sensoria over the course of this program, and of the platforms developed or refined in conjunction with that research, in order to enable the initial SensIT development community.

### 3 WINS NG 1.0 Sensor Development Platform

To quickly supply the SensIT community with a development system to enable testing of networked sensor algorithms early in the WINS NG program, we developed and supplied the WINS NG 1.0 sensor development platform. This platform leveraged Sensoria Corporation's past development experience in order to supply this platform to the community starting in December 1999. Features of the platform are summarized below with further details provided in the following sub-sections.

<p><b>WINS Network Nodes</b></p>  <p><b>WINS Next Generation Node (WINS NG)</b></p>	<p>The WINS Node is the intelligent, ubiquitous networked device of the Computing Continuum.</p> <p>The <b>WINS Node</b> provides the direct and distributed interfaces to the physical world. The WINS NG System is a unique architecture that provides:</p> <ul style="list-style-type: none"><li>• <i>Physical Interfaces:</i><ul style="list-style-type: none"><li>• Multiple analog sensor interfaces</li><li>• Multiple parallel digital interfaces</li><li>• Multiple serial digital interfaces</li><li>• Global Positioning System (GPS)</li></ul></li><li>• <i>Computation and Signal Processing</i><ul style="list-style-type: none"><li>• Real time preprocessor</li><li>• 32 bit processor and operating system</li></ul></li><li>• <i>Communication and Networking</i><ul style="list-style-type: none"><li>• 2.4 GHz frequency hopped spread spectrum low power communication</li></ul></li><li>• <i>Energy and Platform Management Systems</i></li><li>• <i>Local Graphical User Interface</i></li><li>• <b>WINS Gateway</b><ul style="list-style-type: none"><li>• Programmable network interfaces to networks including Ethernet</li></ul></li></ul>
---	---

## WINS Development Platforms



The WINS NG Development platform includes Ethernet and serial access to WINS NG Node development ports providing a networked workstation development environment.

- *WINS Server*
- *WINS SQL Server*
- *WINS Web Access*

The WINS NG 1.0 network architecture, shown in Figure 1, includes WINS NG Nodes, Gateways, Server and Web access components. WINS NG nodes have been distributed in the environment for threat detection, identification, and location during the early stages of the SensIT program. Sensors attach to the WINS node and include seismic, acoustic, and infrared detection. Local signal processing at the WINS node enables constantly vigilant monitoring of sensor signals for detection and identification. Microprocessor systems in the node provide adaptive, distributed computing resources for network management. Finally, a local area, low power wireless modem is designed for support of a messaging network.

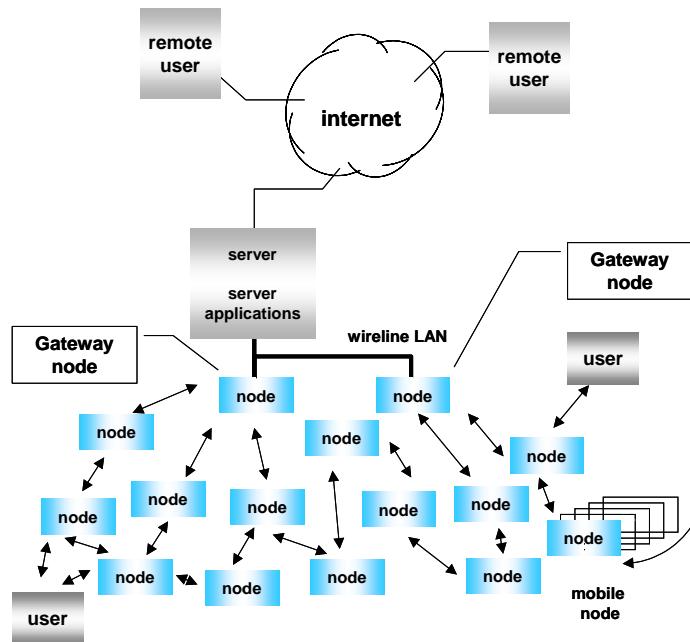


Figure 1. The WINS NG network architecture includes WINS NG Nodes, Gateways, Server and Web access components.

The WINS NG node architecture is shown in Figure 2. This architecture has been developed to provide support for both real-time, constantly vigilant signal processing and support for software

development in non-real time platforms. The architecture diagram shows the sensor, signal processing, and preprocessor components. All of the components, other than the processor, operate at a high or full duty cycle. All of these sensing and signal processing components must continuously monitor the environment for threat status. However, the processor need operate only upon demand. Processor operation may occur to compute a new networking solution, adapt a detection algorithm, or process a complex threat signal. However, this operation may generally be performed at low duty cycle.

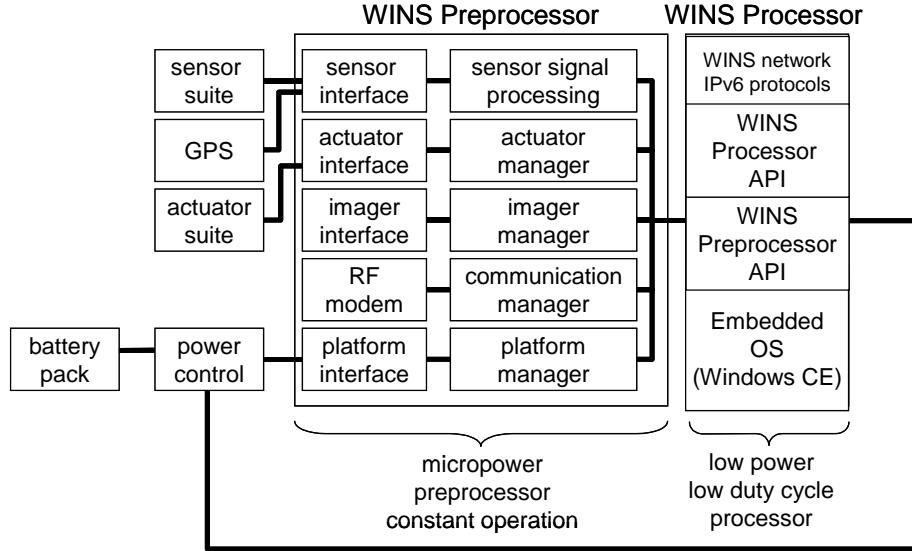


Figure 2. The WINS NG Node Architecture. This architecture has been developed to provide support for both real-time, constantly vigilant signal processing and support for software development in non-real time platforms.

### 3.1 WINS NG 1.0 Platform Components

The WINS NG 1.0 Platform components illustrated in Figure 2 are described further in the following subsections.

### 3.1.1 WINS NG 1.0 Sensors

The original WINS NG 1.0 sensors included a seismic geophone sensor, an acoustic sensor, and an infrared motion sensor system. In addition, a GPS position sensor was also included. Finally, analog input and digital I/O support was provided for contractors who wish to develop custom sensor systems. Further details on the sensing capabilities of the WINS NG 1.0 nodes are shown in Table 1. Each WINS NG node was equipped with a seismic, acoustic, and infrared sensor, as well as a GPS receiver.

The WINS NG Sensors were developed for tactical applications. The sensors and sensor interfaces follow the specifications of devices used in the leading DOD reference tactical sensor data acquisition systems. These systems met or exceeded the performance of the tactical sensors in the field at the time of use within the SensIT program. These threat detection sensors include seismic, acoustic, and infrared motion devices. GPS modules are included as well for location and time references.

<i>Phenomena</i>	<i>Sensor Type</i>	<i>Specifications</i>		<i>Package Type</i>
<i>Seismic</i>	<i>Geophone</i>	<i>Resonant Frequency</i>	10 Hz	<i>External remote sensing case with cable. Two packages are available one with a butterfly tripod, and one with a spike for two sensor-to-surface coupling options</i>
		<i>Coil characteristics</i>	395Ω	
		<i>Peak Responsivity</i>	Velocity responsivity of 0.70 V/in/sec	
<i>Acoustic</i>	<i>Electret compact microphone</i>	<i>Omnidirectional</i>		<i>External remote sensing case with cable.</i>
		<i>Sensitivity</i>	-44dB (0dB=1V/Pa)	
		<i>Frequency Range</i>	20Hz - 20kHz	
		<i>S/N Ratio</i>	>58dB	
<i>Passive Infrared</i>	<i>Pyroelectric infrared sensor</i>	<i>Coverage out to 13.5 m (45 ft). Enhanced 20 V/m RFI immunity with visible light rejection filter</i>		<i>External remote sensing case with cable. Includes a Velcro mount orienting the field of view. Sensor is 7 x 2.8 x 2.5 cm</i>
<i>GPS</i>	<i>12 channel GPS receiver</i>	<i>Update Rate:</i>	10/sec	<i>Integrated into node with six foot cable for magnetic mount antenna placement.</i>
		<i>Cold Start:</i>	1 min. average	
		<i>Warm Start:</i>	40s average	
		<i>Hot Start:</i>	8s average	
		<i>Reacquisition Time:</i>	100ms	
		<i>Minimum Signal</i>	-175 dBW	
		<i>Output:</i>	NMEA Protocol	

Table 1: Summary of WINS NG 1.0 Sensors.

### 3.1.1.1 WINS NG Sensor Interface System Specifications

The WINS NG Node sensor inputs include fully conditioned analog input sampling for tactical sensors. These inputs include amplifiers, controllable anti-aliasing input filters, and input analog to digital converters. The sensor interface specifications are listed in Table 2.

Parameter	Channel	Conditions	Typ	Unit
Gain	Ch 1&2		1=20 2=40 3=58 4=73	dB
	Ch 3&4		1=6 2=20 3=40 4=60	dB
Frequency Response	Ch 1&2	Frequency response is limited by a 5th order Butterworth SC filter. Corner Frequency is determined by the sampling clock: 8.192kHz & 32.768kHz	Low = 81.92 High = 327.6	Hz
	Ch 3&4	Frequency response is limited by a 1-pole RC LPF at the input to the ADC.	2.3kHz	Hz
Input Impedance	Ch 1&2	Both inputs are AC coupled and referenced to 2.5V. Impedance valid above 1Hz	$100 \times 10^3$	$\Omega$
	Ch 3&4	Both inputs are AC coupled and referenced to 2.5V. Impedances valid above 1Hz	$20 \times 10^6$	$\Omega$
Input Voltage Range	Ch 1&2	Both inputs are AC coupled and referenced to 2.5V.	(1.9 - 3.8)	V
	Ch 3&4	Both inputs are AC coupled and referenced to 2.5V.	(0 - 3.5)	V
Input Referred Noise	Ch 1&2	@ 10Hz	20dB=650 40dB=100 58 & 73dB=50	nV/(rtHz)
	Ch 3&4	@ 10Hz	35	nV/(rtHz)

Table 2: WINS NG 1.0 sensor interface specifications.

### 3.1.2 WINS NG Preprocessor

The WINS NG Preprocessor is shown in Figure 3. This includes the Sensor Interface Processor (shown in Figure 4). The Preprocessor is a low power component with sleep control capability. The Preprocessor includes the following components:

**Sensor Interface Processor** including a static CMOS microprocessor and sampling system. The sampling system includes a set of programmable, switched capacitor, analog anti-aliasing input filters.

**Control Processor** including a Z180L - low power microprocessor equipped with 512K SRAM and 128K of flash memory.

**Serial I/O Ports** are included with the Preprocessor.

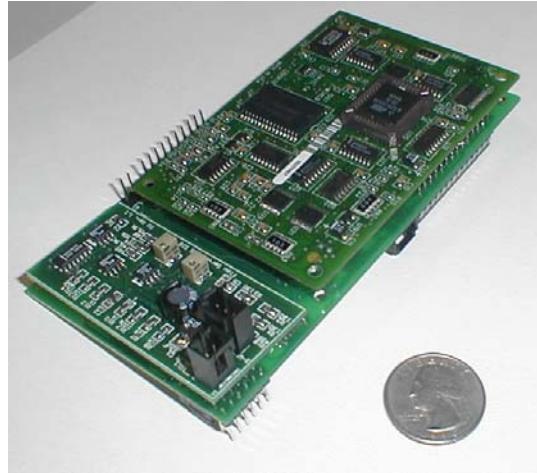


Figure 3. The WINS NG Preprocessor. This includes the Sensor Interface Processor (shown in Figure 4). The Preprocessor is a low power component with sleep control capability.

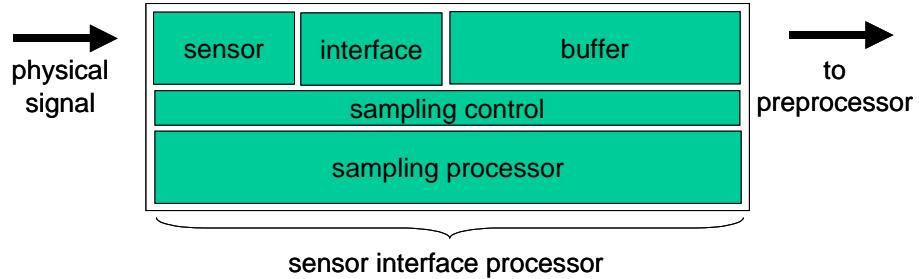


Figure 4. The *Sensor Interface Processor* including a static CMOS microprocessor and sampling system. The sampling system includes a set of programmable, switched capacitor, analog anti-aliasing input filters.



Figure 5. The WINS NG Power Supply. The WINS NG Power Supply is a low power system intended to support a multiplicity of sensors and interfaces with both low average power, and high peak power performance.

### 3.1.3 WINS NG Processor

The WINS NG system operates with a constantly vigilant Preprocessor sampling all sensor data. The Preprocessor is responsible for data acquisition as well as alert functions. Specifically, in the event that a threshold excursion is observed, the Preprocessor detects and alerts the Processor. The Processor, which may have been operating in a sleep state, is now available for signal processing and event identification. Further, high level functions, including: cooperative detection, database

transactions and other services, may now be negotiated by the Processor. At all times, the algorithms may be implemented to minimize power dissipation. The 80 MHz MIPS processor platform has been tested for throughput. The code, which will be supplied in source code as part of the kit at the WINS NG Short Course, includes FIR filters, IIR filters, and a complete spectrum analyzer. Filter generator algorithms will be supplied as well. This will provide the developer with the ability to command the Node to locally synthesize a complex filter without a large demand on communication resources.

Filter throughput requirements depend on network system design. Goals for distributed sensor systems are to reduce the ratio of sampled sensor bits to processed or communicated bits. However, for testing and development purposes, it will be convenient for the WINS NG platform processing speed to match that of the sensor data stream. This would require a processing rate of about 1000 12-bit words per second. FIR filters and FIR filter generators have been implemented with the 32-bit integer data type and the 64 bit double data types. Throughput test results are shown in Figure 6 through Figure 8.

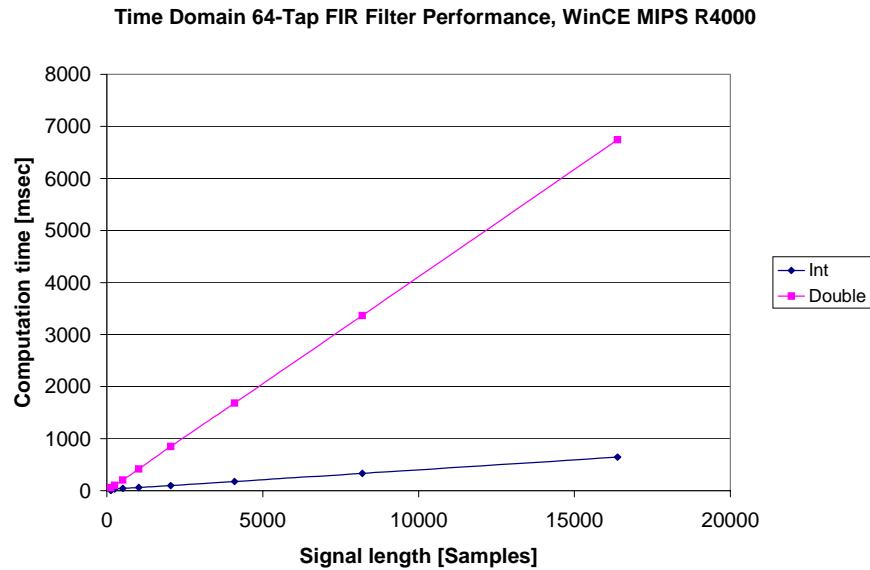


Figure 6. WINS NG Processor throughput test for a 64-tap FIR filter.

**Time Domain 128-Tap FIR Filter Performance WinCE MIPS R4000**

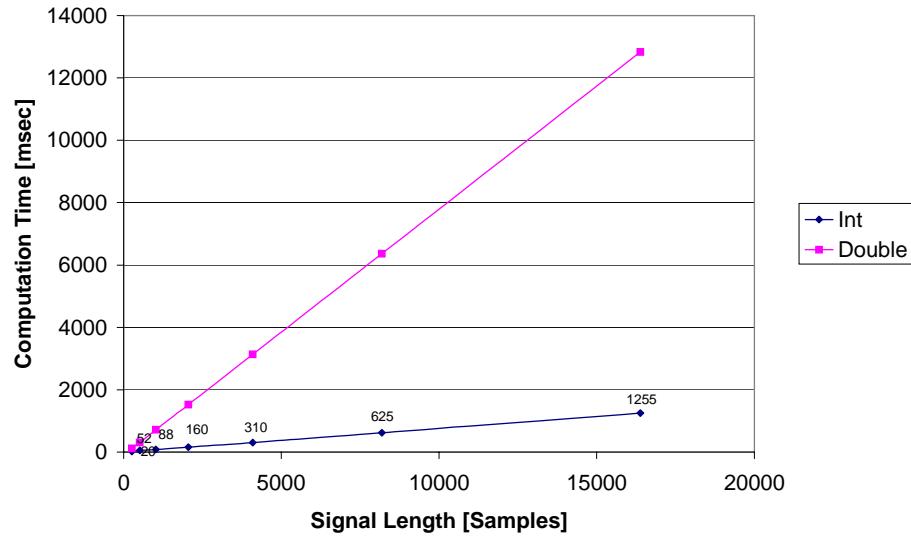


Figure 7. WINS NG Processor throughput test for a 128-tap FIR filter.

**Time Domain 512-Tap FIR Filter Performance WinCE MIPS R4000**

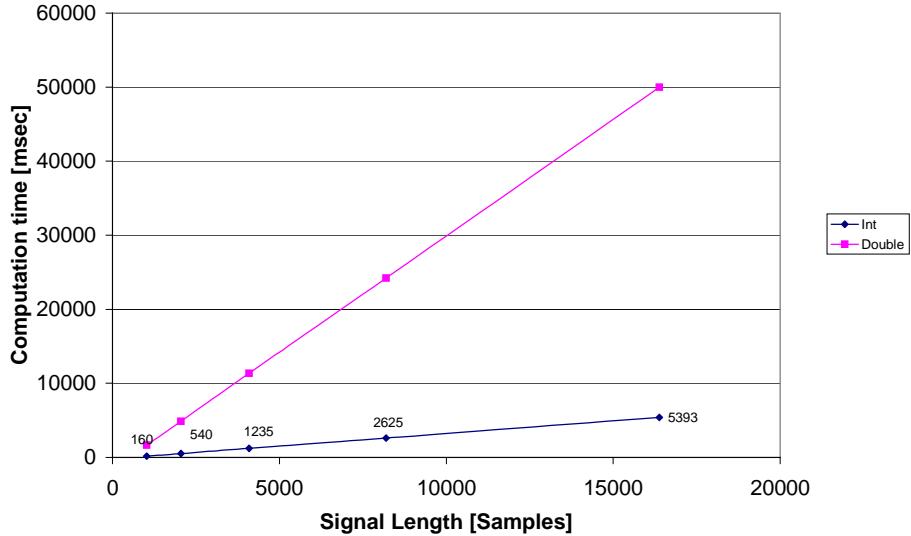


Figure 8. WINS NG Processor throughput test for a 512-tap FIR filter.

It is important to note that even for the extreme case of a 512-tap FIR filter, data throughput matches the incoming word rate for high resolution, 32 bit processing.

The WINS NG Processor is based on a commercial PDA platform, which also provides a user interface at the node, with the following characteristics:

- MIPS R4000 Processor at 80 MHz clock rate

- ROM Memory – 8 MB
- RAM Memory – 8 MB
- Touch Screen
- Windows CE 2.0 OS
- Ethernet Interface

### **3.1.4 WINS NG RF Modem**

The WINS NG RF Modem is a 2.4 GHz frequency hopped, spread spectrum system. Sensor.com has integrated this RF Modem with a dielectric patch antenna system to enable a completely sealed, internal communication solution. This is mechanically robust and convenient for deployment. The WINS NG RF modem is a frequency hopped spread spectrum system operating in the unlicensed 2.4 GHz ISM band. Specifications for the RF modem include:

Signaling:	BFSK
Spread Spectrum:	Frequency Hopping
Hopping Sequence Choices:	50
Addressing:	Programmable
Physical Address:	6 byte permanently assigned IEEE 802.3 address
Operating Band:	2.4000 – 2.4835 GHz
Transmitted Power:	10mW
Receiver Sensitivity:	-90dBm
Range:	Greater than 100m for outdoor and typical indoor environments

#### **RF Modem**

Configuration:	As is required for robust, frequency hopped spread spectrum transceivers, the WINS NG RF modems operate in a master/slave hierarchy, where the master modem provides synchronization for many slave modems. By default, the Gateway modem may function as a master. However, this is not required, nor always optimal. Multihop routing occurs between the clusters that are defined by the current status of the RF modems.
----------------	--

#### **RF Modem**

Configuration Control:	Each WINS NG RF modem may be promoted from slave to master state or demoted from master to slave. This capability is useful in providing reconfigurability and implementing multicluster/multihop communication.
------------------------	--

Number of network nodes supported by single Gateway:	At least 50
Communication Rate:	Defined for Individual Node to Gateway and aggregate of Multiple Nodes to Gateway

(Average bit rate is intended to be low for densely distributed sensors. However, for development purposes, bit rate may be increased. *The WINS NG system is designed to provide the worst-case high bit rate that would occur if no information processing were to occur. This would support continuous streaming of unprocessed sensor data. Information processing will reduce this bit rate for the benefits of scalability and energy.*)

#### Individual Node to Gateway

Communication Rate: Peak air interface data rate will be greater than 100 kbps. Preprocessor to Modem interface data rates will be lower than the air interface data rate. Typical applications will support the filling of the RF modem transmit buffer over a period, followed by communication of the buffer over a short interval available in an appropriate TDMA frame. Additional information and example applications will be provided in the API Specifications.

Complete system speed will support continuous streaming of sampled data for at least one WINS NG node in the network.

Multiple Nodes to Gateway: Multiple user inputs are allowed at the Gateway modem.

Data Frame: Detailed data transfer functions with the RF modem are supported by the WINS NG API, which was supplied. The Data Frame includes the format shown in Figure 9.

Length (low order byte)	Length (high order byte)	Destination Address	Source Address	Data (up to 2048 bytes)	Checksum
----------------------------	-----------------------------	------------------------	-------------------	----------------------------	----------

Figure 9. WINS NG Data Frame. Unicast and Broadcast addressing are supported.

### 3.1.5 WINS NG Package

The WINS NG Package is a sealed, waterproof system that Sensor.com and the DOD have employed for tactical sensors in field applications. The Package contains the WINS Preprocessor, Processor, and Sensors. Sensors may also be deployed externally to the package (particularly in the case of acoustic and infrared motion sensors.)

While equipped with rechargeable batteries, a battery eliminator is included with WINS NG for operation during development.



Figure 10. The WINS NG environmentally resistant package. Sensors are placed external to this package for optimal performance.

## 3.2 WINS NG 1.0 Software API

The WINS NG Software API architecture has been developed and is shown in Figure 11. The API includes low level functions for access to physical world interfaces, as will be described. The API also includes higher level functions and finally the support for the full SensIT Applications.

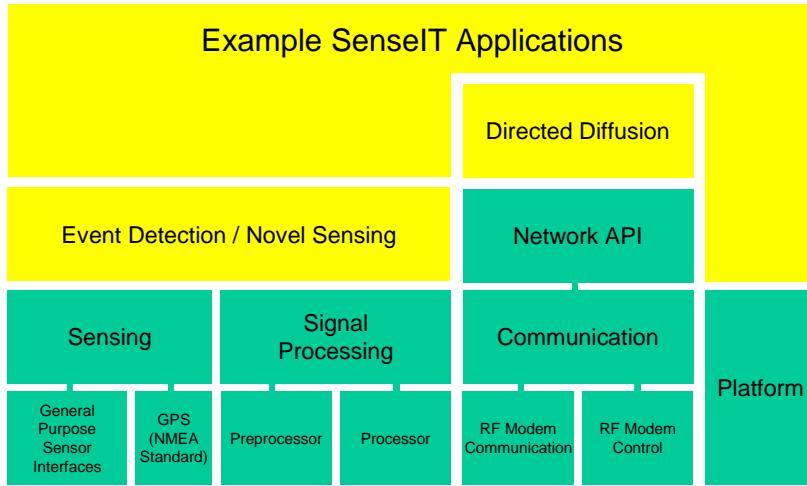


Figure 11. The WINS NG API is shown including low-level functions for access to physical world interfaces and support for the full SensIT Applications.

### 3.2.1 WINS NG Framework Application: WINS NG 1.0 API

To fully demonstrate the use of the WINS NG APIs, an application was provided with the platform. This application, referred to as the SensIT Framework, contains access to functions including sensing, analog-to-digital conversion control, automatic gain control, GPS access, networking, and platform control. Each interface provided a demonstration of these API functions.

## 3.3 WINS NG 1.0 Node Power Dissipation Specifications

Figure 12 shows power dissipation for WINS NG 1.0 subsystems for all subsystems operating at full power and 100 percent duty cycle. This data may be used to select subsystem duty cycle. Depending on operating mode, whether standby, vigilant, or full alert, each of the subsystems may be placed into a sleep (power off) state.

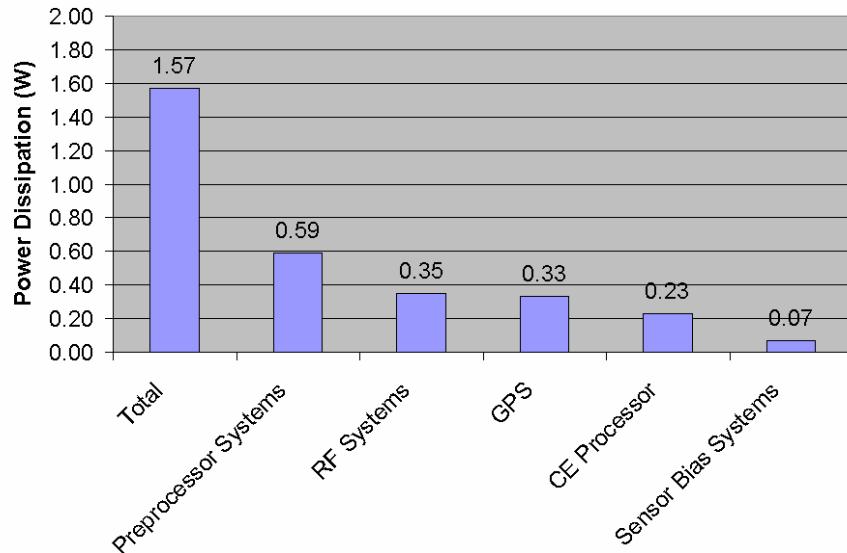


Figure 12. WINS NG 1.0 Power dissipation by subsystem

### 3.4 WINS NG 1.0 Deployment at SITEX00

As part of the SensIT program, 37 WINS NG 1.0 nodes were setup at the Marine Corp Air Ground Combat Center (MCAGCC) in 29 Palms California, operating for over two weeks in August of 2002. This represented the first field experiment for the SensIT program and was a combination data collection experiment, algorithm testing, and deployed system experiment. Part of the area (an intersection of three roads) is shown in Figure 13.



Figure 13. View from the command area of the SITEX test site at the MCAGCC, 29 Palms CA.

During SITEX00, each of the WINS NG nodes was deployed off the ground to reduce temperature at the node (as shown in Figure 14), powered off of marine cells (connected to multiple WINS NG 1.0 nodes so they could be left for weeks out in the field), and connected over Ethernet back to a base camp so all data collected could be stored and the operation of each node monitored.

An example of the large amount of data collected as a variety of military targets passed on the road (both planned and unplanned data collection targets) is shown in Figure 15. For this experiment multiple data runs were collected including targets of personnel, personal vehicles, AAVs, LAVs, HMMWVs, Dragon Wagons, a variety of trucks, and an occasional tank. During these data runs, the WINS NG 1.0 nodes were the primary data collection instrument, and also enabled the testing of distributed, embedded operation of detection and networking algorithms. The distribution of WINS NG 1.0 nodes during SITEX00 can be seen in Figure 16, for which the detections seen at local nodes as an AAV passed are shown, as well as in Figure 17, where a close-up of the intersections is shown with passive infrared detections of personnel.



Figure 14. WINS NG 1.0 node as setup and left for 2 weeks during SITEX00.

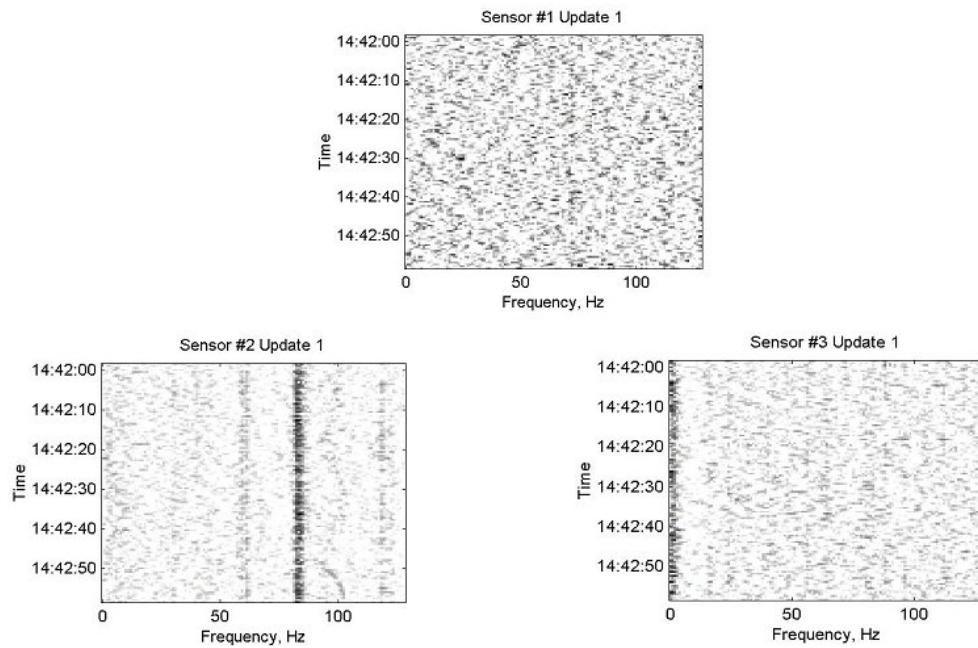


Figure 15. Example data collected from a seismic (#1), acoustic (#2), and passive infrared (#3) sensor on a WINS NG 1.0 node at SITEX00.

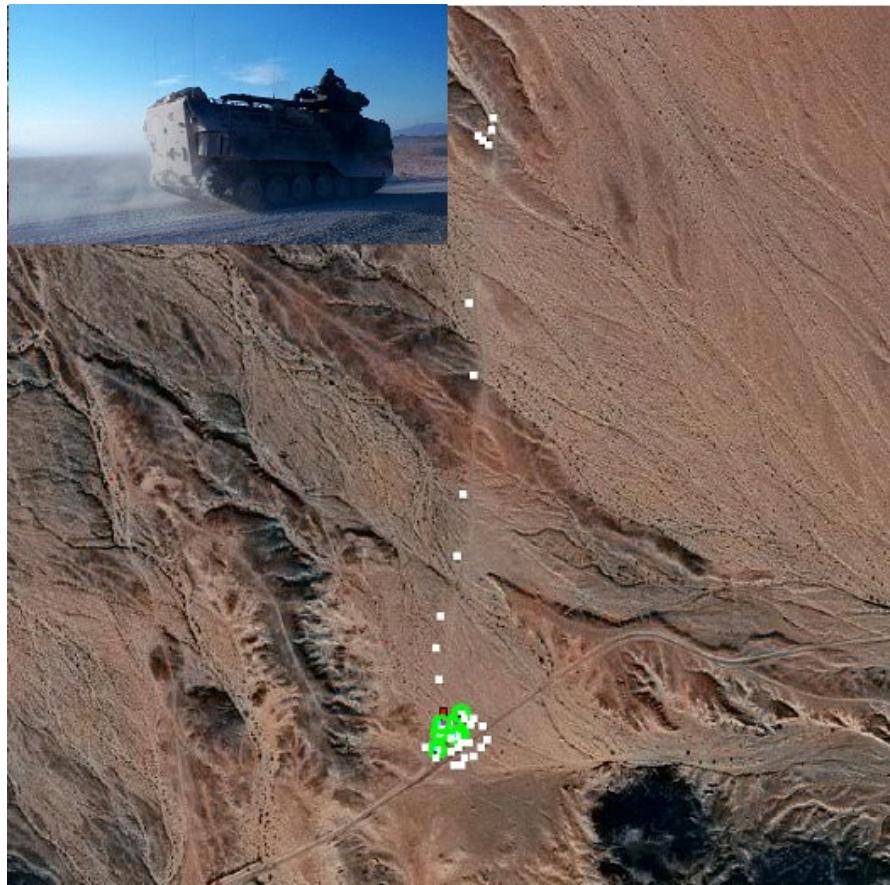


Figure 16. Display of data collected on WINS NG 1.0 nodes as an AAV (shown in the inset) passed. Sensor detections are shown with green circles and colors coordinated to the sensor detection type, with node locations shown in white.

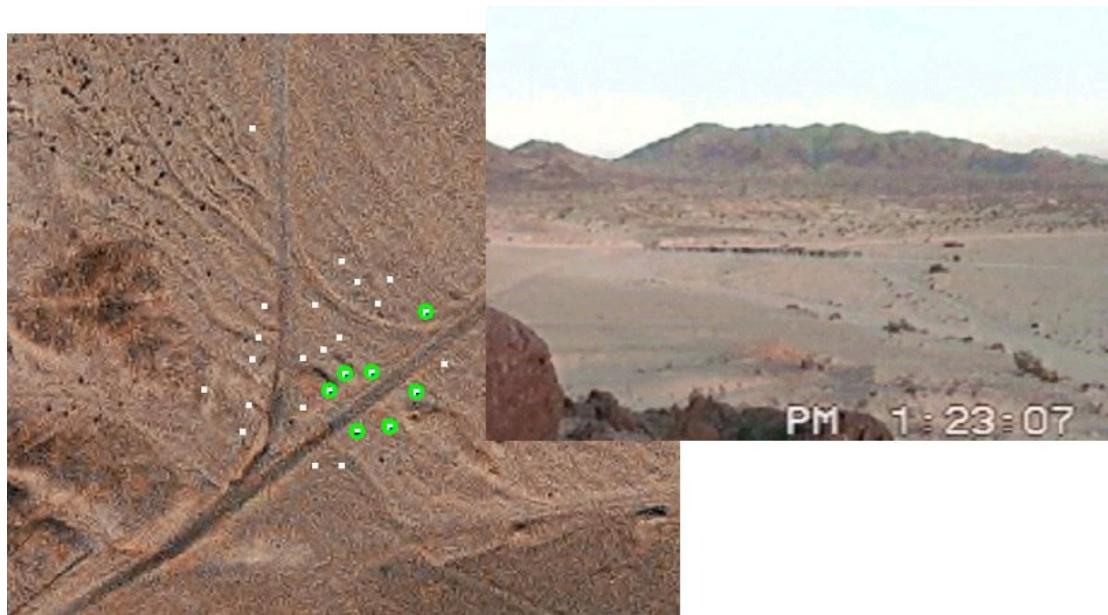


Figure 17. Display of Infrared detections by WINS NG 1.0 nodes as a column of infantry (shown in the time-stamped picture) pass.

### 3.5 WINS Imager

To complement the WINS NG 1.0 sensor development nodes we provided to SensIT, the Sensoria WINS Imager, developed previous to the WINS NG program, was also provided to the SensIT community and further refined within the early part of the WINS NG program. The WINS (Wireless Integrated Network Sensor) Imager provides remotely operated imaging capability over multi-kilometer distances. The Imager system is pictured in Figure 18. The Imager consists of three components: the remotely deployed CCD image capture system, the wireless modem attached to a laptop over a serial interface, and the software GUI to enable communication with and control from the attached laptop computer. The WINS Imager provides the capability to trigger image capture through a local wired input, such as a fluctuation on a passive IR sensor, or through a remote request on the wireless channel, or though activation via a wired connection to a nearby WINS NG 1.0 node.

#### 3.5.1 Imager Architecture

The WINS Imager system is pictured in Figure 18. The system consists of the remotely deployed Imager (A), the wireless modem to which the interface responds and transmits images (B), and the software control running on a workstation (C) to view and request pictures through the attached modem. The remote Imager provides both a wireless interface to request pictures as well as a local interface to trigger picture operation. Shown in Figure 18, the Imager is triggered with a passive infrared detector. Additional triggering options are shown in Figure 19. These include a wide-angle infrared detector, a narrow beam infrared detector, a locally triggered switch corresponding to the different triggering conditions associated with the TASS system, and a wired connection to an autonomous WINS NG 1.0 node to enable local processing and autonomous decisions about image acquisition.

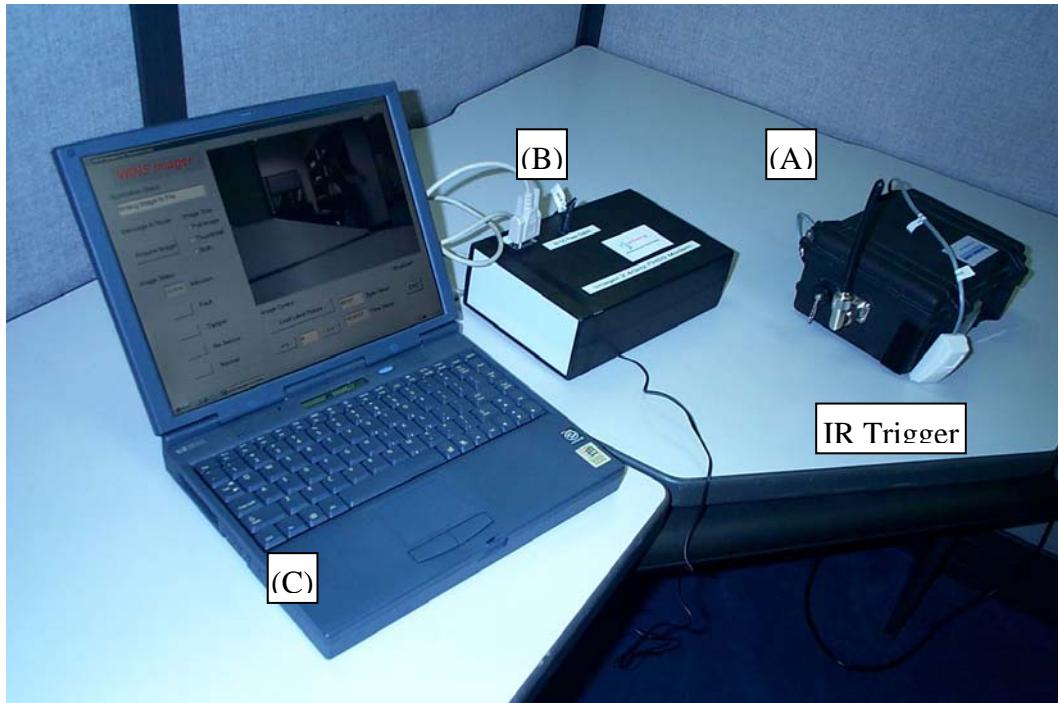


Figure 18. WINS Imager Setup with passive infrared trigger.



Figure 19. Imager triggering options. All are interchangeable.

The Sequence of events in the WINS Imager operation is as follows.

- The Imager receives a request to trigger, either remotely from the laptop interface, or through one of the local triggering options shown in Figure 19.
- The Imager acquires an image at a fixed delay after the request was made.
- The Imager communicates with the laptop through the modem with notification of a picture. At the instant the laptop receives this notification it time stamps the picture.
- The image is uploaded to the laptop. During this process the Imager software GUI displays the progress of picture transfer in terms of the number of bytes received (see Figure 20).

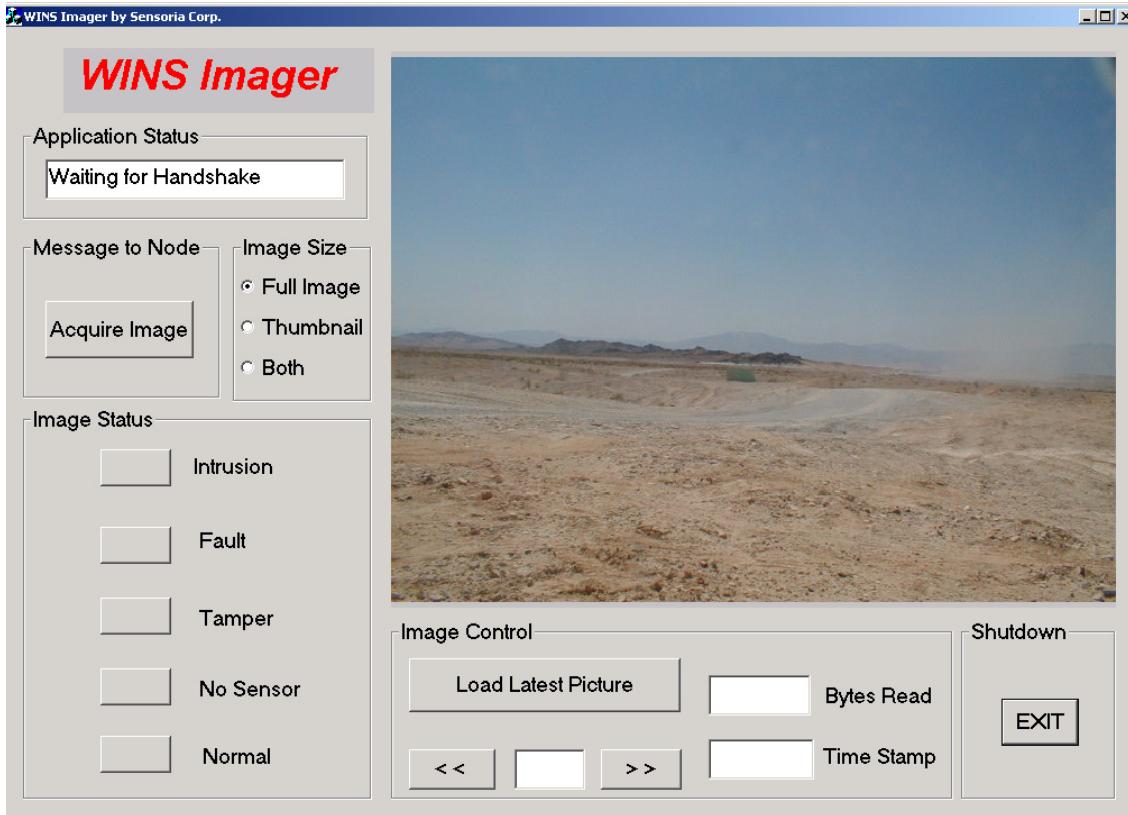


Figure 20. WINS Imager stand-alone Laptop interface.

### 3.5.2 Imager Software

The WINS Imager software GUI is shown in Figure 20. The interface provides both display and control capabilities. Images may be transferred as a thumbnail, a full image, or both after they are taken, depending on the trigger cause. A number of different image triggers are supported. These correspond to the five options dictated by the TASS system, for which the Imager was initially developed. Additionally, the interface provides the capability to load the last picture taken after the GUI is restarted and to cycle through the pictures as the images are being taken.

In addition to providing the GUI shown in Figure 20, Sensoria has also provided a sockets interface so that each of the commands and controls of the GUI may be seamlessly integrated into another developer's interface or sensor system. This facilitates development of complete systems integrating the Imager capability, with additional sensing and distributed decision-making. In the sockets interface, there are two functions that a programmer will need to use in order to communicate with the WINS Imager Server Program; `SendWINSImager` and `ReceiveWINSImager`. These two programs let a developer interface with the GUI of Figure 20, when the GUI is minimized in order to provide all the functionality and response incorporated into the WINS Imager GUI.

### 3.5.3 Imager Network

The WINS Imager transmits status updates, requests, and images taken to the attached FHSS 2.4GHz modem. This modem requires a 9V input (through the included 120V AC to 9V DC adapter) in addition to a serial interface to the laptop on which the WINS Imager software is

operating. The Imager to modem link has been demonstrated operating robustly over a 1.5km link, with the Imager on the ground and the modem near the peak of a nearby hill, without line of sight between the two antennas. The 1.5km demonstrated link is seen in the picture on the Imager display of Figure 20, where the modem was on the hill off in the distance and the Imager was placed on the ground. Distances out to 10km are achievable with judicious placement of the Imager and modem for an optimal line of sight link.

The WINS Imager modem of Figure 18 (B), includes an antenna within the RF permeable packaging. The Imager itself uses an omni-directional detachable dipole. Increased range links between the two units may be most easily achieved by elevating both units.

### 3.5.4 WINS Imager Specifications

Specifications on the capabilities of the WINS Imager utilized in the early part of the SensIT program as part of the WINS NG program are given in Table 3 to Table 7.

<b>Focus range</b>	<i>4 in. – infinity</i>
<b>Horizontal FOV</b>	<i>55 °</i>
<b>Vertical FOV</b>	<i>39 °(19.5 °half-angle off the ground)</i>
<b>Recording Image</b>	<i>640 x 480 pixels</i>
<b>Shutter Speed</b>	<i>½ - 1/500 sec. (mechanical shutter)</i>

Table 3: CCD Solid-state Image Pickup Element.

<b>Battery Lifetime</b>	<i>50+ pictures continuous use 4+ hour standby operation*</i>
<b>Battery charging time</b>	<i>12 hours from uncharged**</i>
<b>Adapter</b>	<i>120V 60Hz to 12V DC in</i>
<b>Power Draw</b>	<i>130mA at 12V idle 500mA at 12V for 1s while capturing image 425mA for 50-60s while transmitting image***</i>
<i>*With remaining battery power to take and transmit at least one picture, for this number the radio and processor is always on.</i>	
<i>** Charging for 2 hours from uncharged allows one picture, 50+ pictures are available after 12 hours.</i>	
<i>***Dependent on image size, which is dependent on image contrast and brightness</i>	

Table 4: Remote Camera Power Specifications.

<i>Temperature</i>	<i>0 – 40 °C (operating)</i> <i>-20 – 60 °C (storage)</i>
<i>Humidity</i>	<i>20-90% (operation)</i> <i>10-90% (storage)</i>

Table 5: WINS Imager operating environment.

<i>Delay in Time Stamping</i>	<i>Image time stamped at Laptop 4s after image is taken</i>
<i>Delay in requesting through a WINS NG 1.0 Node</i>	<i>2300±100ms*</i>
<i>Delay in Requesting from the Laptop</i>	<i>15s average, ranges from 2.5s to 22s**</i>
<i>Delay in triggering from IR or switch</i>	<i>2100±200ms***</i>
<i>Time Stamp Set</i>	<i>By the laptop clock, 4s after picture is taken</i>
<i>Minimum time between pictures</i>	<i>71s</i>
<i>Time to download thumbnail when triggered locally</i>	<i>12s after the picture is taken</i>

\*Limited by Windows CE delay variation in switching threads. This was measured with automatic triggering based on Windows CE timing, and with data sampling stopped and the radios off on the 1.0 node to limit latency.

\*\*Latency variability results since the Imager not the modem initiates communication, and communication is duty cycled to reduce battery drain.

\*\*\* Higher consistency expected, this measured value is limited by the human error in the triggering measurements

Table 6: Timing Specifications.

<i>Interfacing Laptop OS</i>	<i>Windows 2000/ Windows NT</i>
<i>Recommended Laptop Speed</i>	<i>350MHz Pentium II or higher</i>
<i>FHSS radio Transmit Power</i>	<i>1W in the 2.4-2.4835GHz ISM band</i>
<i>Thumbnail size</i>	<i>4048 Bytes</i>
<i>Full Image Size</i>	<i>40-65 kBytes</i>

Table 7: WINS Imager General Specifications.

### 3.5.5 Use of the WINS Imager at SITEX01

The WINS Imager system was integrated with a Base Station and power systems for deployment at the SensIT Situational Experiment (SITEX00 and 01) in conjunction with the WINS NG 1.0 development nodes. The capabilities of this integrated system include:

1. WINS Imager Base Station Display

2. Wireless access to a remote position at Base Camp Promontory
3. Local cueing of WINS Imager with local sensor inputs and remote Imager control and image acquisition

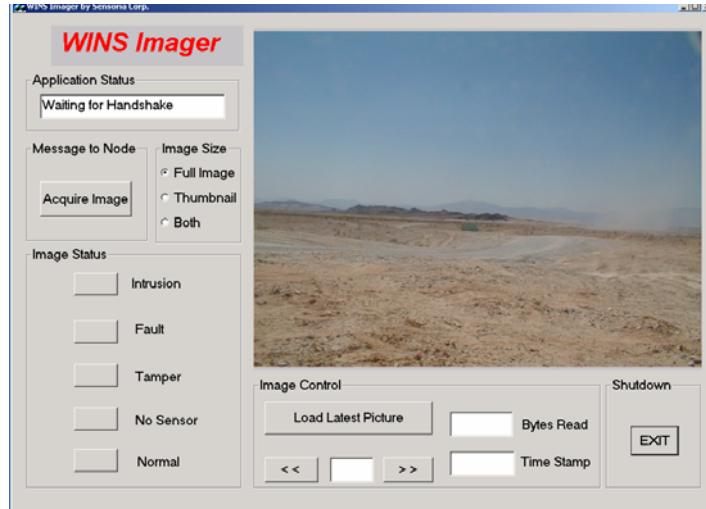


Figure 21. WINS Imager Base Station User Interface. This base station was located at the Base Camp Promontory shown below.

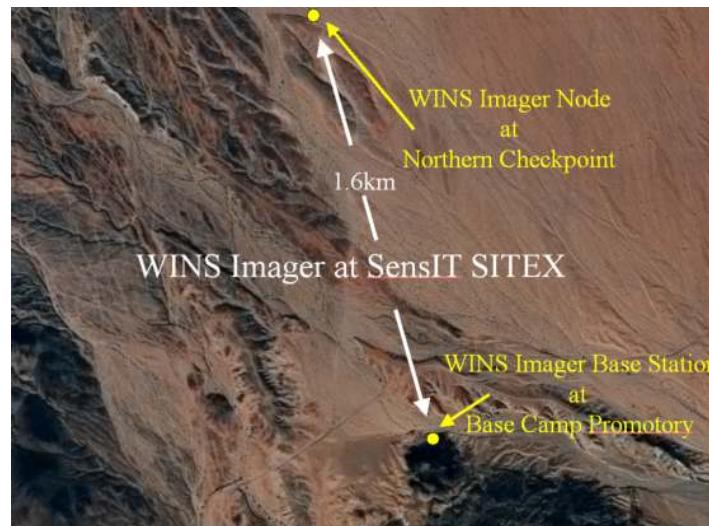


Figure 22. SITEX00 demonstration area, indicating the deployment of the WINS Imager and the Base Camp Promontory sites.



Figure 23. Typical images obtained with the WINS Imager operating at the remote site in the SITEX exercise.

### 3.6 WINS NG 1.0 Summary

The SensIT community utilized sixty of the WINS NG 1.0 development platforms plus one WINS Imager prototype in the first year of the program. During the use of these platforms, a number of lessons were learned, and research progressed on the development platform APIs, on the platform capabilities, and on the network support. These lessons learned within Sensoria Corporation were combined with user feedback from the SensIT community to develop and produce the WINS NG 2.0 sensor development platform and WINS 2.0 Imager discussed in the following section.

## 4 WINS NG 2.0 Sensor Development Platform

The WINS NG 2.0 sensor development platform represented a significant upgrade to the 1.0 platform. The WINS NG 2.0 system leverages the development within the 1.0 system, for example the preprocessor/processor architecture to separate real-time tasks from the processor, and includes significant upgrades such as: extensive networking improvement and scalability support, significantly enhanced sensing resolution and capability, migration to the Linux OS with significantly expanded development tools, and enhanced hardware and software flexibility and capability of the development system and networked sensor nodes. A summary of the capabilities of the WINS NG 2.0 platform is provided in the sub-sections below.

The WINS (Wireless Integrated Network Sensors) NG version 2.0 Platform provides a development platform for networked embedded systems. The WINS NG platform is designed to provide the capability for 1) monitoring many input sensor signal streams, 2) processing these input streams, 3) performing local computation for physical event recognition, 4) performing local computation and processing for local area wireless networking, and 5) communication of messages, sensor data, and code. The WINS NG platform hosts the software systems that support signal processing, cooperative event detection, novel networking, and other distributed computing capabilities. The WINS NG 2.0 system includes high performance analog sensor sampling, sensor digital signal processing, a scalable dual channel spread spectrum wireless network solution, a 32-bit application processor and a POSIX-compliant operating system.

### 4.1 Adaptive Node Platform

The WINS NG 2.0 node platform architecture includes a Real Time Interface Processor<sup>TM</sup>, improving on the capabilities of the preprocessor provided in the WINS NG 1.0 nodes. This device supports high-speed multi-port sampling integrated with both a high speed DSP and direct digital

I/O. The architecture also includes a 32-bit Application Processor with RAM, ROM, and flash memory. Digital I/O and GPS geolocation capability is provided with an attached active antenna. The WINS NG 2.0 wireless network interface includes an adaptive dual mode RF modem system that enables a solution for scalable, multihop networking with spread spectrum signaling. A block diagram for the WINS NG 2.0 platform is shown in Figure 24. Shown in Figure 25 is the Real Time Interface Processor (a) and Application Processor (b) printed circuit boards.

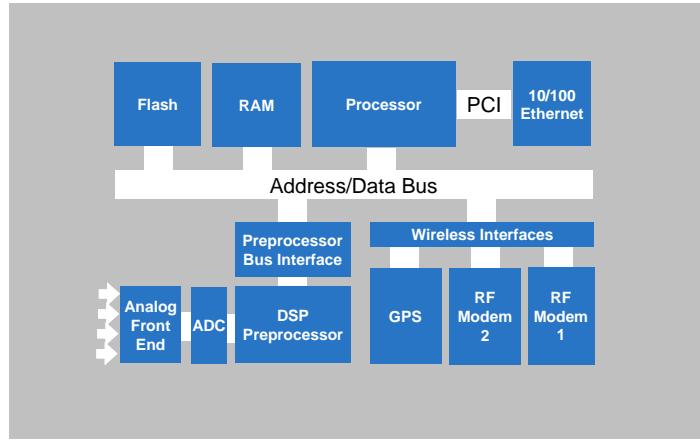


Figure 24. Block diagram of the WINS NG 2.0 platform

The capabilities of the WINS NG 2.0 node processor are summarized in Table 8. These capabilities represent an upgrade over the WINS NG 1.0 platform, providing significantly more developer flexibility and capability.

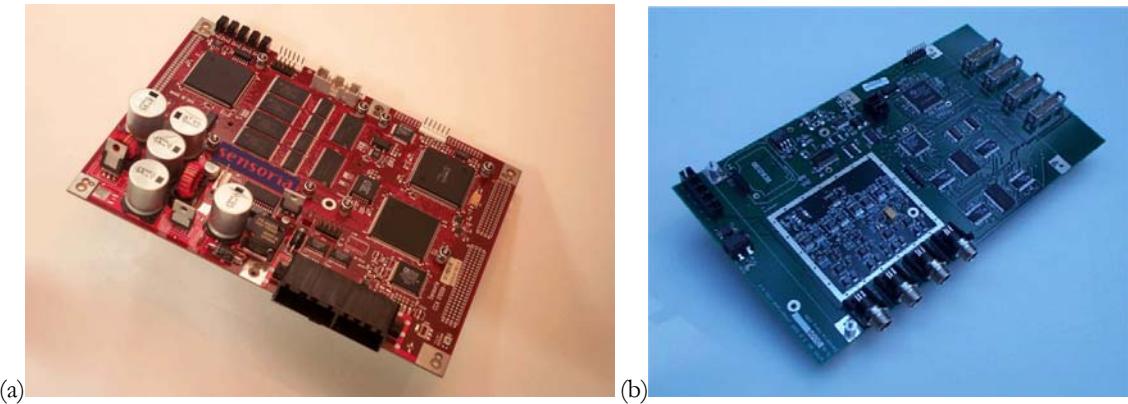


Figure 25. (a) WINS NG 2.0 Processor Core and (b) Sensor Interface System

Platform Processor Core	Hitachi SH-4 7751
Platform Memory	16MB RAM, 16MB Flash
Processor Architecture	32bit RISC architecture Superscalar dual issue architecture Low power consumption with 1.8V internal, 3.3V I/O bias Branch operations: folding, prediction, conditional prefetch 16K data cache and 8K instruction cache Memory Management Units (MMU) Floating Point Unit with Single and Double Precision
Processor Performance	Core: 300 MIPS Floating Point Unit: 1.1 GFLOPS
Processor Power Dissipation	400 mW

Table 8: Processor specifications for the WINS NG 2.0 node.

## 4.2 Adaptive Analog Sensing and Signal Processing Platform

The WINS NG 2.0 analog sensor interfaces include high-speed sampling interfaces. This provides high-speed sampling up to 15.5 bit ENOB resolution. The high-speed channel employs separate preamplifiers and anti-aliasing filters for each channel. Analog input sampling provides 80 ksps that can be spread across all four channels, so that each channel can be concurrently sampled at 20 ksps. The specifications of the adaptive analog sensing system for the WINS NG 2.0 nodes are provided in Table 9 and Table 10.

The WINS NG 2.0 sensor data input stream operates at bandwidth well above the level that is practical for signal processing in general purpose embedded processors to provide development flexibility. The sensor front-end high-speed input sample rate is accommodated in a power-efficient approach with a dedicated, programmable digital signal processor (DSP); the industry standard Texas Instruments 5402. This DSP is supplied with an integrated development environment. DSP code may be communicated to the platform via a developer port or directly via the wireless network. The DSP enables local processing of high bandwidth sensor data (up to 20k samples/sec per channel input). The DSP enables a low power solution for detection and identification of events by the sensor input suite.

DSP software development is straightforward, using standard C-code compiled on Texas Instrument's Code Composer Studio (CCS). Programming under DSP/BIOS, multiple processes can be supported and managed in real-time using API's supplied with CCS. Hardware and software interrupts, along with multitasking services, mailboxes, queues, semaphores, and resource protection, can all be viewed graphically in real-time for fast development.

Industry standard tools support the WINS NG 2.0 DSP platform. Tools and development boards are available to support developers who are building signal processing and event detection capabilities. In addition, design flexibility is provided on the WINS NG 2.0 system via a sensing API

available on the main processor, such that initial development can be conducted with standard Linux tools (compiled for the SH4) prior to porting code to the TI DSP.

<b><i>High Speed S/H ADC</i></b>	
<b><i>4-ch differential front-end</i></b>	
<b><i>Resolution</i></b>	<b><i>16bits*</i></b>
<b><i>Sample rate</i></b>	<b><i>20kHz</i></b>
<b><i>Selectable gains</i></b>	<b><i>2,11,101,1001V/V (6dB, 20.8dB, 40.1dB, and 60.01dB)</i></b>
<b><i>Selectable output word rates</i></b>	<b><i>20K, 10K, 5K, 2.5K, 1.25K, 625, 312.5, 156.25Hz</i></b>
<b><i>Digital LP filtering and decimation for word rates below 20kHz</i></b>	
<b><i>Fixed 8th order Butterworth anti-alias filter</i></b>	<b><i>-0.2dB @ 5kHz -3dB @ 6kHz -35.5dB @ 10kHz</i></b>
<b><i>Input noise voltage</i></b>	<b><i>15 nV/rt(Hz)</i></b>
<b><i>Linearity metric to front-end (Independent Linearity Error)</i></b>	
<b><i>Gain non-linearity</i></b>	<b><i>20ppm**</i></b>
<b><i>ADC Integral non-linearity</i></b>	<b><i>Max ± 6LSB</i></b>
<b><i>*Lower resolution at higher output word rates. (ENOB effective number of bits)</i></b>	
<b><i>4ch @ 20kHz ENOB=12 bits</i></b>	
<b><i>1ch @ 20kHz ENOB=13.5 bits</i></b>	
<b><i>1ch @ 1.25kHz ENOB=15.5 bits</i></b>	
<b><i>** Maximum deviation from best fit line</i></b>	

Table 9: WINS NG 2.0 analog-sampling specifications.

<b>Processor</b>	Low power digital signal processor control system
Frequency (MHz)	80
MIPS	80
Data & Program Memory	16k internal 128k external words (x16 bit addresses per word) External memory shared between host and DSP
Arithmetic and Logic Unit	40-Bit
Software System	Software implemented for sampling management only. Unprocessed sensor data provided to Processor.

Table 10: WINS NG 2.0 adaptive analog section specifications.

## 4.3 Adaptive RF Network

Integrated within every WINS NG 2.0 node is a dual mode RF modem. The modems provide the basis for a scalable multi-cluster, multi-hop network. The dual mode approach solves the long-standing problem that restricts spread spectrum modem solutions to local cluster/star networks. The dual channel modem approach allows every node to participate in two networks simultaneously, thus reducing latency in multi-cluster communication. The two networks are unsynchronized. However, frequency hopping reduces the likelihood of collisions to a negligible level. The dual mode modem enables development of low latency multi-cluster communication and provides two overlapping independent sets of networks. Every node may be configured as a base or a remote for each network.

The WINS NG 2.0 system operates in the 2.4-2.4835GHz ISM band transmitting at 100mW or 10mW on dual channels. Detailed specifications on these modems are included in Table 11. The WINS NG 2.0 platform is supplied with a baseline network and RF modem configuration. However, additional flexibility is provided to enable developer system refinement for particular network wireless applications, as they desire. In addition, the WINS NG nodes provide the expandability to support 802.11 PCMCIA cards as an alternative network as discussed below in section 4.4.

Each of the two integrated RF modems within a WINS NG 2.0 node provides a peak air interface rate of 460 kbps. However, the sustained, continuous throughput is 56 kbps per channel for two channels.

In addition to the integrated RF modems and expansion support for PCMCIA cards, such as 802.11b, the WINS NG 2.0 system also provides wireline interfaces with both 10 Mb Ethernet and serial port access.

<b>Frequency</b>	<b>2.4-2.483GHz</b>
<b>Coding</b>	<b>Frequency Hopped Spread Spectrum (FHSS)</b>
<b>FCC Certification</b>	<b>FCC part 15.247, ETS 300-328 and RSS210 rules, license free</b>
<b>Channel Data Rate</b>	<b>56kbps node to node</b>
<b># of frequency channels</b>	<b>75</b>
<b>Independent networks</b>	<b>64 (for both modes)</b>
<b>RF Bandwidth</b>	<b>750kHz</b>
<b>Transmit power</b>	<b>10mW or 100mW</b>
<b>Outdoor operating Range</b>	<b>25m worst case (zero elevation, cluttered, no LOS) 100m surface-to-surface LOS 500+m elevated with line of sight</b>
<b>Indoor operating range</b>	<b>25m-100m</b>

Table 11: WINS NG 2.0 specification for each of the two integrated RF modems.

### 4.3.1 WINS NG 2.0 Networking

The WINS (Wireless Integrated Network Sensors) NG version 2.0 Platform provides a development system designed to facilitate a low latency multi-hop network configuration. Due to the requirement

for synchronization, all available point to multipoint wireless systems currently operate in a base and remote or star configuration, as shown in Figure 26. The master-slave or base-remote configuration ensures that multiple radios can talk to one another by fixing the synchronization mechanism dictated by the base and all its associated remotes. In order for a node to talk with any node outside its individual cluster the node must synchronize to a separate communication link (separate base and remote cluster). In the 2.0 nodes, this is done by enabling each node to operate on two star networks concurrently so that packets can be routed quickly between clusters (each consisting of a base and its associated remotes, as shown in Figure 27). In order to provide low latency packet transmission, the dual network access is provided with dedicated hardware, rather than by expanding the complexity of each individual modem. This provides a robust, scalable extension of the single cluster architecture (a cluster corresponding to a synchronized channel between nodes), with the flexibility to support a large development community. The focus of the 2.0 platform is to provide a usable baseline configuration in the short term, while providing the capabilities for software customization to meet requirements as they arise.

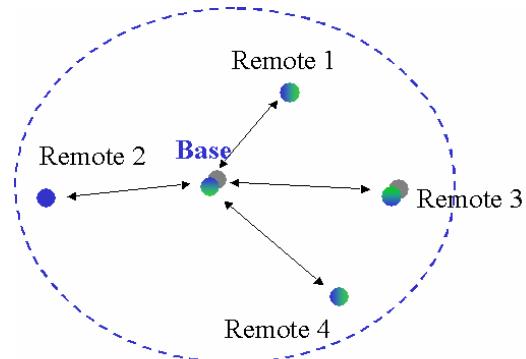


Figure 26. Illustration of the Base and Remote building block for the network architecture.

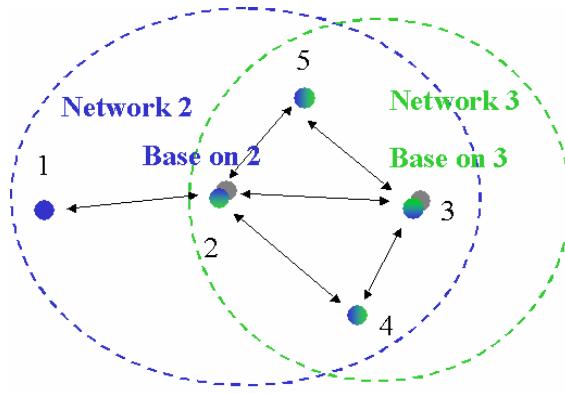


Figure 27. Illustration of dual node networks showing all one-hop paths between bases and remotes.

#### 4.3.1.1 Individual Modem Operation

The WINS NG 2.0 node employs two independent modems per node. Each of these modems operates with Frequency Hopped Spread Spectrum (FHSS) signaling. The hopping is distributed over 75 channels within the 2.4GHz to 2.4835GHz worldwide ISM band at a hopping rate of once per 14.375ms. Communication between base and remotes is synchronized within a TDMA cycle within

each hop. At the beginning of a hop, the base transmits first a synchronization signal, then any data in its buffer, followed by transmissions in TDMA time slots from each of the remotes synchronized by that base. The number of remotes dictates the time slot assigned to each remote and hence the packet size sent, with the transmission set up to operate efficiently with up to 8 remotes. Larger number of remotes per base can be used. However, communication efficiency drops as the header size occupies increasingly large portions of each packet. While the base and remote channel is TDMA, from the API perspective, the radios appear to communicate in full duplex mode as transmitted and received packets at a single modem are interleaved.

When a modem is powered on and assigned to a specific network as a base, it acquires any remotes within range on the same channel that are not already synchronized with another base. Similarly, any remotes that are powered synchronize with any existing bases on their networks. Once every 256 hops, each remote re-registers with the base, so that if a remote disappears after being in the network, it will be noticed within 4s. Similarly, if a base disappears, since it sends out synchronization signals each hop, its associated remotes will notice its disappearance immediately. Within the 2.0 nodes, the modems appearance and disappearance on the wireless channel is provided through the API as connect or disconnect packets generated by each internal modem when they are no longer synchronized with a specific base or remote.

Within the modems, each packet is sent with an ARQ scheme that retransmits any lost packets at the physical layer up to 16 times based on a 24bit checksum. The number of retransmissions is configurable, to modify communication as desired. However, the ARQ is only enabled for point-to-point transmissions. While every transmission from a remote to its associated base is point-to-point and hence uses the ARQ if configured, transmissions from a base to a remote may be point-to-point (if a specific node is addressed) or broadcast, in which no retransmission is implemented. A one-byte checksum is also provided at the driver layer that can be utilized if error checking is desired at higher layers. Additional feedback on the channel is provided through the RSSI option of the radio API. This provides the power level averaged over the last ten frequency hops seen by a remote. The RSSI value is not defined at a base, because each base may be communicating with multiple remotes, while each remote only communicates with a single base. The RSSI value is the ten-hop average of the regular synchronization header transmitted from the base at the start of each hop.

The power draw of the RF modems is dependent on their operational status. In the default mode of 100mW transmit power, the power cost associated with operating a base (without transmitting anything other than synchronization packets) is 420mW, compared to 90mW for a modem to operate as a synchronized remote. In addition, the cost to transmit data between nodes is approximately 20mJ/kbit at the base side, and 50mJ/kbit at the remote side.

The 2.0 radio API provides access to setting the operational status of each modem (base or remote, transmit power, network, etc.). However, a default operational status will also be provided based on a deterministic node lay out, as well as based on the autonomous clustering described in section 4.3.2.

#### 4.3.1.2 Multi-Hop Network

Within the WINS NG 2.0 node, two modems operate simultaneously; each on an independent network or cluster. The RF Modem API documents how each of these modem drivers can be accessed independently. The dual architecture facilitates passing information between clusters and allows messages to be passed between networks. For example, as illustrated in Figure 28, the dual modem nature of each node provides multiple paths between nodes. Additionally, by transferring messages between each modem driver on a node, a message can be passed over many hops; for example, from node 1 to node 8 by passing through nodes (1,2,3,6,8 i.e. through radios a,c,d,f,k,l,o). Since the dual modems operate independently, the latency in message passing is reduced to that required to route information between each modem driver. The header of each packet passed up

through the radio API enables directed routing as well as providing for packets to be passed along in a broadcast mode at each step of the process.

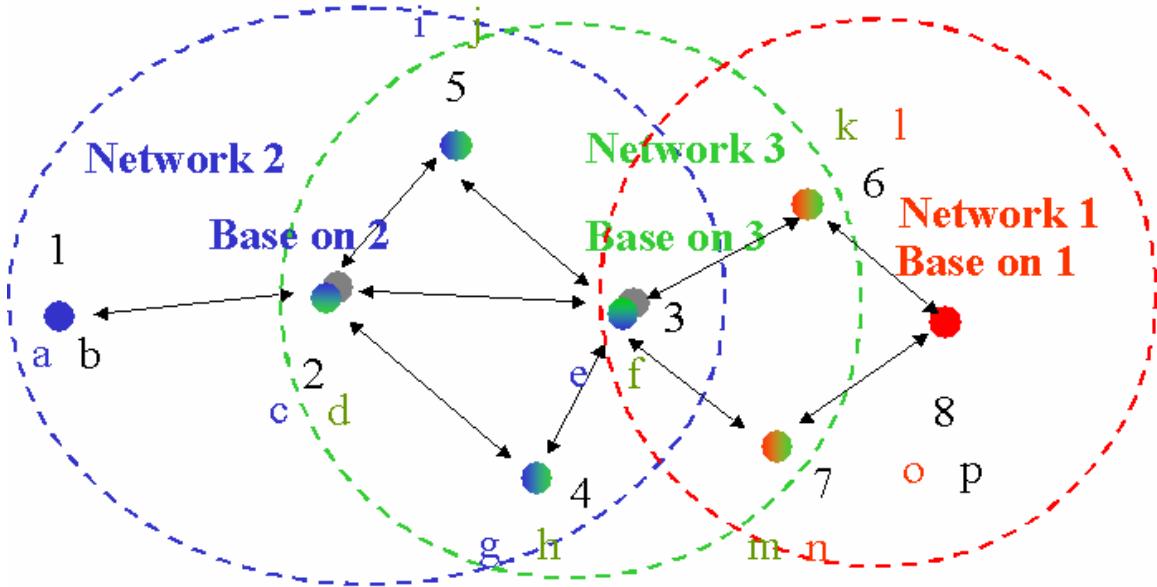


Figure 28. Illustration of three overlapping networks. Node numbers are shown in black with each associated RF modem labeled with letters.

Since each node is operating two independent modems, each node also has two RF addresses. At the RF modem API level, everything is referred to the RF address. For example, rather than labeling the nodes in Figure 28 with node numbers 1-8, the associated radios would be addressed by the radio addresses a-p (in the figure radios b and p are not assigned a network). This provides flexibility in building up a routing table based on associated neighboring radio addresses. The RF modem API provides the capability of returning all the radios connected to a given radio. However, it is not specified which nodes those radios are attached to at the API level. The capability is provided to pass messages between the individual radios, to ascertain which nodes they are associated with, in order to build node driven routing tables. Additionally, a default network operation can be downloaded to each node for initial demonstration and experimental purposes.

To alleviate the complication of adhoc network assembly, each node was initially provided with a default network and radio status, based on a preconceived node lay down. Network assembly after nodes are deployed in an adhoc fashion is also provided as described in the following section. Thus, for example, Figure 28 could provide a deterministic network for a sample node layout. It is then easily seen based on the deterministic layout which radio IDs are associated with which nodes. This also can be used to ensure optimal connectivity across multiple clusters.

#### 4.3.2 Automatic Cluster Formation

While for some applications static configuration of clustering may be the best approach, in many cases it is inconvenient to set up a static configuration. In these cases, it may be helpful to utilize the cluster formation module to automatically configure the network parameters for a group of nodes.

The clustering module operates through the radio drivers to setup the communication network autonomously. This module sets the RF modem parameters to form local communication clusters in order to ensure communication is possible across the network. The RF modems operate in a TDMA cycle controlled by a base unit, communicating to a number of remote units as described above. The clustering module autonomously determines which WINS NG 2.0 modem should act as the cluster synchronizer, based on whom it can directly communicate. The clustering module assigns each modem first as a passive listener within each cluster (as a remote to determine if another node is synchronizing the network), then, based on with whom each modem can communicate, either becomes a base to which other nodes can synchronize or synchronizes to another node which has become a base. The clustering module listens for a random period of time for other radios before attempting synchronization, requires a minimum number of other available nodes to synchronize with (“minimum number of remotes per cluster” option with the current radios), and cycles between listening and attempting synchronization until each cluster stabilizes.

The clustering module uses heartbeats passed between nodes to monitor the status of the RF link in order to determine if it should re-assemble the network. In the event of a change in network topology (one node is turned off, or runs out of energy), the network will reassemble with the available nodes. The clustering module uses only two frequency-hopping patterns: network 5 and network 6. This streamlines the implementation of the autonomous cluster formation.

By default, the clustering algorithm will require a minimum of one remote per cluster. Depending on the type of topology expected, and depending on application requirements, it may be desirable to require that clusters contain more than one remote. This can be configured using the -n option, which enables the user to force each cluster to have at least N remotes. Table 12 summarizes the options in using clustering on the WINS NG 2.0 nodes.

Description	Option Syntax	Default
Number of “Network A”	-a <0-63>	5
Number of “Network B”	-b <0-63>	6
Minimum number of remotes per cluster	-n <1-10>	1

Table 12: WINS NG 2.0 autonomous clustering options

#### 4.3.2.1 Recommended Practices For Using Clustering

The WINS NG 2.0 clustering is based on a statistical connection between nodes, built up from local connectivity. As a result, multi-hop connectivity is not ensured for every topology. However, simple practices can be utilized to improve the connectivity for a WINS NG 2.0 node lay out.

The most limited RF communication will generally occur for WINS NG 2.0 nodes when they are placed in indoor settings and when they are placed outdoors on the ground. In both cases, RF propagation can be modeled, to the first order, with a fourth-order power fall off with distance, giving a worst-case maximum range between base and remote nodes of 30 to 50m. In a number of environments this maximum range will be much greater (up to 4km in line of sight conditions). However, the 30m to 50m range provides a baseline link distance.

In order for clustering to effectively connect nodes with a stable link, enough possible connections between nodes must be available at less than the maximum range. In addition, use of the “minimum number of remotes” option can decrease the fraction of nodes operating as bases, changing node interconnectivity. As a general rule, node spacing of 25m or less with nodes distributed over an area

(as opposed to in a line) will fully connect with the supplied clustering algorithm. If the nodes are deployed in a single line, increasing the antenna heights, reducing the inter-node spacing, and increasing the minimum number of remotes option to two will all improve the stability and inter-connectivity of the network. The default minimum number of remotes set at one enables cluster formation with only two WINS NG nodes, as well as provides effective clustering for well separated nodes evenly distributed over an area.

#### 4.3.3 The Sensoria Visualization Tool used with WINS NG 2.0

The Sensoria Visualization Tool GUI provides detailed feedback for debugging problems with the network in moving from simulation to actual deployment. A screen capture of the GUI is shown in Figure 29. As shown in the figure, each node with Ethernet connections (130, 135, and 129) displays the base/remote status of its radios (bases are either blue or red boxes; remotes are white boxes), displays the RSSI value seen by each remote, and provides lines indicating if one-way or two-way communication is currently available (the red and blue arrows). In the figure, it can be seen that nodes 130 and 133 are bases, although 133 is not shown as blue since it is not connected via Ethernet. In addition, not shown in this screen shot, the Sensoria Visualization tool also displays the timer values in the clustering algorithm described in the previous sub-section for each radio (on nodes connected over Ethernet) to illustrate whether the network has stabilized or is still forming. Since all information for the visualization tool is obtained over Ethernet connections, the monitoring of the RF network does not impact its performance. However, due to this restriction, RSSI and timer information can only be obtained for nodes to which there is an Ethernet connection, and network connectivity is only based on connectivity information gathered from Ethernet-connected nodes.

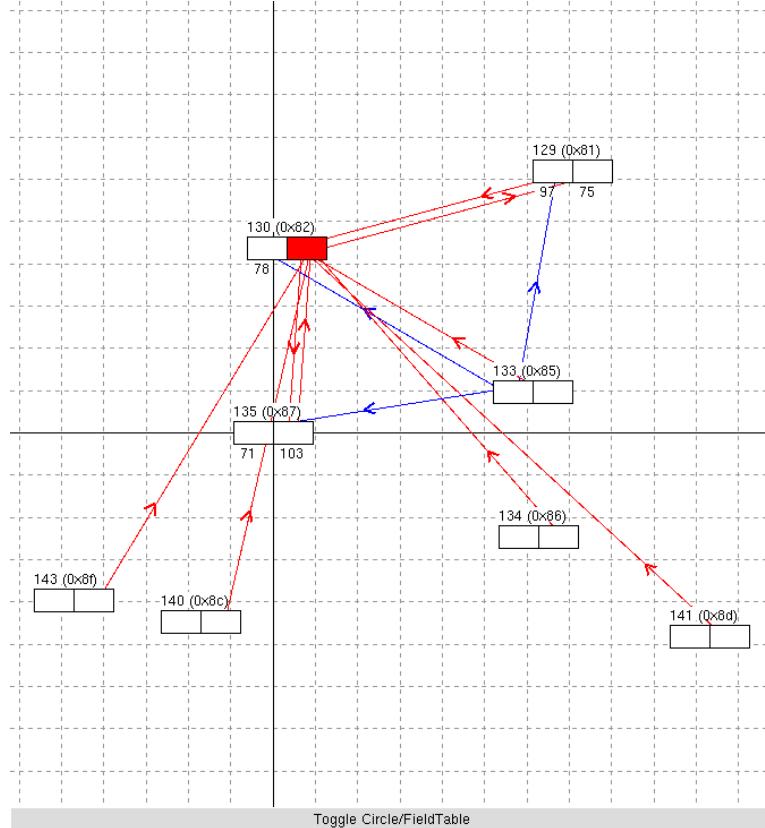


Figure 29. Screen capture of the Sensoria visualization GUI.

## **4.4 802.11b Wireless Network Interface Setup for WINS NG 2.0 Nodes**

A WINS NG 2.0 may be configured to operate using a number of different RF communication options. An alternative to using the embedded RF modems for wireless communication is to equip a WINS NG 2.0 with one or two PCMCIA 802.11b cards.

Any standard 802.11b card that is supported under Linux is expected to be compatible with this build, if operated in infrastructure mode<sup>1</sup>. However, in most multihop applications, these cards need to be operated in ad hoc mode.

## **4.5 WINS NG 2.0 Software Development Environment**

The WINS NG 2.0 system provides both a hardware platform and software APIs. Node development may be conducted through the node Ethernet port or an RS232 diagnostic port.

The WINS NG 2.0 platform supports the Linux operating system with the 2.4 kernel version. Services including a ramdisk, flashfile system, Ethernet networking, NFS file access, and development compiler and debugger tools have been developed and are supplied.

A large set of Linux packages have also been installed and tested, and these include packages for both the development platform and the WINS NG 2.0 node, enabling an array of developer support on this embedded platform.

For the development platform (which can be a normal x86 PC), the packages and their applications include:

- 1) binutils
  - a) Basic utilities including linker and profiler
- 2) cracklib
  - a) Tests passwords to determine whether they match certain security-oriented characteristics
- 3) glibc
  - a) GNU C-library
- 4) libtermcap
  - a) Basic system library needed to access the termcap database. The termcap library supports easy access to the termcap database, so that programs can output character-based displays in a terminal-independent manner.
- 5) ncurses
  - a) Clone of System V Release 4.0 (SVr4) "cursor optimization". Library of functions that manage an application's display on character-cell terminals (e.g., VT100).
- 6) openssl
  - a) Secure sockets layer
- 7) pam
  - a) Security tool for authentication of SMB file access

---

<sup>1</sup> For definition of terms for wireless LAN operation please refer to IEEE 802.11 standards documents.

- 8) popt
  - a) C library for parsing command line parameters
- 9) pwdb
  - a) password database library
- 10) slang
  - a) S-Lang extension language static libraries and header files. S-lang is a C-like screen-handling language.
- 11) tcl
  - a) TCL scripting language
- 12) tcp\_wrappers
  - a) Access control
- 13) zlib
  - a) Data compression

For the WINS NG 2.0 node, the packages and their applications include:

- 1) SysVinit
  - a) SysVinit includes the init program, the first program started by the Linux kernel when the system boots. Init then controls the startup, running, and shutdown of all other programs.
- 2) bash2
  - a) Shell
- 3) bzip2
  - a) File compression
- 4) e2fsprogs
  - a) Utilities for managing the second extended (ext2) filesystem
- 5) fileutils
  - a) Basic directory
- 6) ftp
  - a) File transfer
- 7) glibc
  - a) C library
- 8) gzip
  - a) File compression
- 9) inetd
  - a) The inetd package contains the inetd networking program. Inetd listens on certain Internet sockets for connection requests, decides what program should receive each request, and starts that program.
- 10) initscripts
  - a) The initscripts package contains the basic system scripts used to boot, change run levels, and shut the system down cleanly. Initscripts also contains the scripts that activate and deactivate most network interfaces.

- 11) mingetty
  - a) Opens tty lines and sets their modes, prints the login prompt, and gets the user name to initiate a login process for the user.
- 12) mktemp
  - a) The mktemp utility takes a given file name template and overwrites a portion of it to create a unique file name. This allows shell scripts and other programs to safely create and use /tmp files.
- 13) modutils
  - a) The Linux kernel allows new kernel pieces to be loaded and old ones to be unloaded while the kernel continues to run. These loadable pieces are called modules, and can include device drivers and filesystems among other things. This package includes program to load and unload programs both automatically and manually.
- 14) net-tools
  - a) This is a collection of the basic tools necessary for setting up networking on a Linux machine. It includes ifconfig, route, netstat, rarp, and some other minor tools.
- 15) ntsysv
  - a) ntsysv provides a full-screen tool for updating the /etc/rc.d directory hierarchy, which controls the starting and stopping of system services.
- 16) passwd
  - a) Password services
- 17) setserial
  - a) Set serial port configuration
- 18) sh-utils
  - a) Shell scripting utilities

### ***Utilities used in typical shell scripts***

- 19) sysklogd
  - a) The sysklogd package contains two system utilities (syslogd and klogd) which provide support for system logging. Syslogd and klogd run as daemons (background processes) and log system messages to different places, (sendmail logs, security logs, error logs, etc.).
- 20) file archiving
  - a) telnetd
- 21) Telnet daemon
  - a) util-linux
- 22) zlib
  - a) Compression

## **4.6 Power Specifications**

To support the development community, each WINS NG 2.0 node has been supplied with a lead acid battery, which can supply power to the nodes. The characteristics of this battery platform are shown in Table 13. In addition, each of these battery packages can be configured to supply double density, effectively doubling the lifetime figures of Table 13.

<b>Battery Lifetime</b>	<b>3 hour continuous use 20 hour standby operation</b>
<b>Battery charging time</b>	<b>5 hours from uncharged</b>
<b>Adapter</b>	<b>120V 60Hz to 12V DC in</b>

Table 13: Operational lifetime of the WINS NG 2.0 nodes using its supplied battery.

## 4.7 GPS Technical Specifications

As in the WINS NG 1.0 nodes, the WINS NG 2.0 nodes include an integrated GPS receiver and active GPS antenna, with a six-foot cable to provide flexibility in GPS antenna placement. Specifics of the GPS receiver in the WINS NG 2.0 nodes are shown in Table 14.

<b>Received codes:</b>	<b>L1, C/A code</b>
<b>Channels</b>	<b>12</b>
<b>Max Solution update</b>	<b>10/s (1/s standard)</b>
<b>Satellite Reacquisition Time</b>	<b>100ms</b>
<b>Snap Start</b>	<b>&lt; 2 seconds</b>
<b>Hot Start</b>	<b>&lt; 8 seconds average</b>
<b>Warm Start</b>	<b>&lt; 38 seconds average</b>
<b>Cold Start</b>	<b>&lt; 45 seconds average</b>
<b>Minimum signal tracked</b>	<b>-175 dBm</b>
<b>Maximum altitude</b>	<b>&lt; 60,000 feet</b>
<b>Maximum velocity</b>	<b>&lt; 1000 knots</b>
<b>Protocols</b>	<b>NMEA v2.2</b>
<b>Position Accuracy</b>	<b>10 meter 2dRMS, WAAS enabled 1-5 meter, DGPS corrected</b>
<b>GPS antenna cable length</b>	<b>6 feet</b>

Table 14: Specifications for the GPS system included with the WINS NG 2.0 nodes.

## 4.8 WINS Imager 2.0

The WINS NG program has been very successful with the development of the WINS NG 2.0 node that dramatically exceeds the performance and development support capabilities of any other available contemporary wireless embedded systems technology. WINS NG 2.0 has been designed and implemented to support the SensIT program that includes requirements for a highly capable, multiple network port, low power, standalone embedded wireless system. It includes wireless networking, analog sensing, an open operating system, and infrastructure API software. In addition,

the SensIT community requested Sensoria Corporation, to provide an Imager that cleanly interfaces with the WINS NG 2.0 network. This Imager provides “eyes on target” when triggered by lower energy sensors, as the final point in an automated sensing hierarchy, when a notification of an event is passed up out of the network. A picture of this WINS 2.0 Imager is shown in Figure 30 atop a WINS NG 2.0 battery pack.



Figure 30. WINS 2.0 Imager atop a battery pack.

The WINS 2.0 Imager provides support for demonstrations of algorithms developed within the SensIT program operating on the WINS NG 2.0 Sensor Platform. As such, it interfaces to the WINS NG 2.0 network described above, provides the same functionality as a WINS NG 2.0 node, and provides an API documenting the features of the Imager available to processes running on the sensor nodes to capture, modify, and transport acquired pictures.

The WINS 2.0 Imager nodes support all the capabilities of the WINS NG 2.0 nodes (dual radio architecture, sensing, GPS, operating system, and hardware), in addition to containing imaging hardware and an interface to imaging functions, including triggering the nodes at predetermined times and sending the acquired pictures over the RF network.

The WINS 2.0 Imager builds on Sensoria Corporation’s experience in providing a prior version of Imager to support demonstrations on the WINS NG 1.0 sensor nodes as described in section 3.5. Details of the improvements incorporated into the 2.0 Imager are provided in the next section.

#### 4.8.1 Improvements over the Prior Sensoria WINS Imager

The WINS 2.0 Imager represents a substantial improvement over the prior version of the Sensoria Imager developed outside of the SensIT program. The prior Imager was designed to meet the requirements of a TRSS sensor network, where local sensors supplied the impetus to trigger the Imager, and then refined in the early stages of the WINS NG program. As part of this prior effort, a single prototype imager was constructed with a dedicated point-to-point radio link to pass a picture to a remote observer. The WINS 2.0 Imager provides the flexibility not provided by the prior WINS 1.0 Sensoria Imager. It interfaces directly with a WINS NG 2.0 node to provide a mechanism for power control (power savings), to enable local processing on a 2.0 node or passing along the image over the WINS NG 2.0 radio network, to reduce the latency in image acquisition, and provide more

flexibility as to how many pictures of what resolution are taken. In addition, as only a single prior imager was developed, the WINS 2.0 Imager development optimized the Imager system to support the SensIT program, by leveraging current COTS imaging components for increased performance and providing multiple imagers to support demonstrations to reduce the probability of a hardware component failure compromising future demonstrations. The WINS 2.0 Imager architecture is outlined in the next section.

#### 4.8.2 The WINS 2.0 Imager Architecture

The WINS 2.0 Imager is integrated with the WINS NG 2.0 platform such that a WINS NG 2.0 imager may acquire an image upon command and recover this image into the WINS NG 2.0 file system. At this point, the image is available to be transported over Ethernet or the WINS NG wireless network. The WINS 2.0 Imager is also compatible with WINS NG 2.0 power systems, and leverages a WINS NG 2.0 node to provide power saving capability; i.e. the attached WINS NG 2.0 node can power up and power down the imaging sub-system as needed.

Figure 31 describes the integrated WINS Imager and node architecture. The WINS 2.0 Imager imaging sub-system is packaged into a WINS NG 2.0 node and connects to the processor via an Ethernet 100MB link, while providing an external Ethernet port as on the current WINS NG 2.0 nodes. This architecture enables the Imager to be separately controlled as an independent module of the 2.0 node, while sharing the same battery and providing a high speed interface for transferring pictures from the Digital Imager to the node's SH4 processor. In addition, this layer of separation allows Sensoria Corporation to leverage the resources in the open source community for coordinating timing on the CMOS digital Imager, over the imager interface, to ensure low latency picture acquisition. Specifications for the WINS 2.0 Imager are provided in Table 15.

<b>Image</b>	<i>640 x 480 CMOS digital imager 24-bit color or 8-bit monochrome 1 frame per 2s</i>
<b>Imager Interface</b>	<i>10/100Mbps telnet, ftp, TCP, IP, and UDP clients CMOS Digital Imager power control</i>
<b>Features</b>	<i>variable Compression ratio variable exposure time with auto focus text overlay</i>

Table 15: WINS 2.0 Imager specifications.

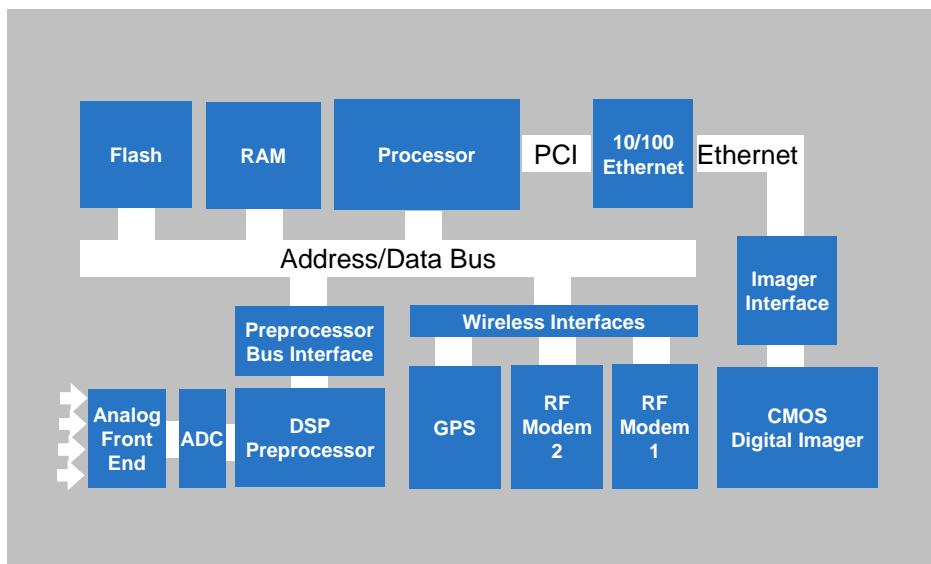


Figure 31. WINS 2.0 Imager architecture.

The WINS NG 2.0 Imager includes an API that provides access to the Imager capabilities from the standard WINS NG 2.0 platform. This API support calls across the Ethernet connection and includes:

- A command to trigger the imager at a set time. This may include a single picture or sequence of pictures. Incorporated in this command is a transfer of acquired images to the WINS NG 2.0 node processor.
- Power Control of the Imager. This includes power up and power down features to conserve energy. Thus, the CMOS digital imager may only be powered up when images are desired.
- Optional access to image control features such as exposure time, image compression, and text overlay.

All API commands are supported on the Linux OS running on the WINS NG 2.0 nodes.

#### 4.8.3 Steel Knight WINS Deployment Status Report

The WINS Imagers were deployed at the Sensor site shown in Figure 32 as part of the Steel Knight combined arms exercise at the MCAGCC at 29 Palms in December 2001. The Imagers are designated as 1 and 3 in this image. The locations of the OP Kumar relay site and the Command and Operations Center (COC) are shown. The network architecture to provide pictures from the remotely deployed imagers of all vehicles passing on an access road is shown in Figure 33.

In conjunction with the WINS 2.0 Imager node, the Steel knight deployment also utilized a long range 802.11b link setup by BBN, as illustrated in Figure 33, to provide a link from both Imagers to the COC, and a web interface operating on a laptop at the COC. The capabilities of that web interface developed by Sensoria Corporation are illustrated in the following sub-sections, each describing a webpage of that interface.



Figure 32. Steel Knight deployment aerial view

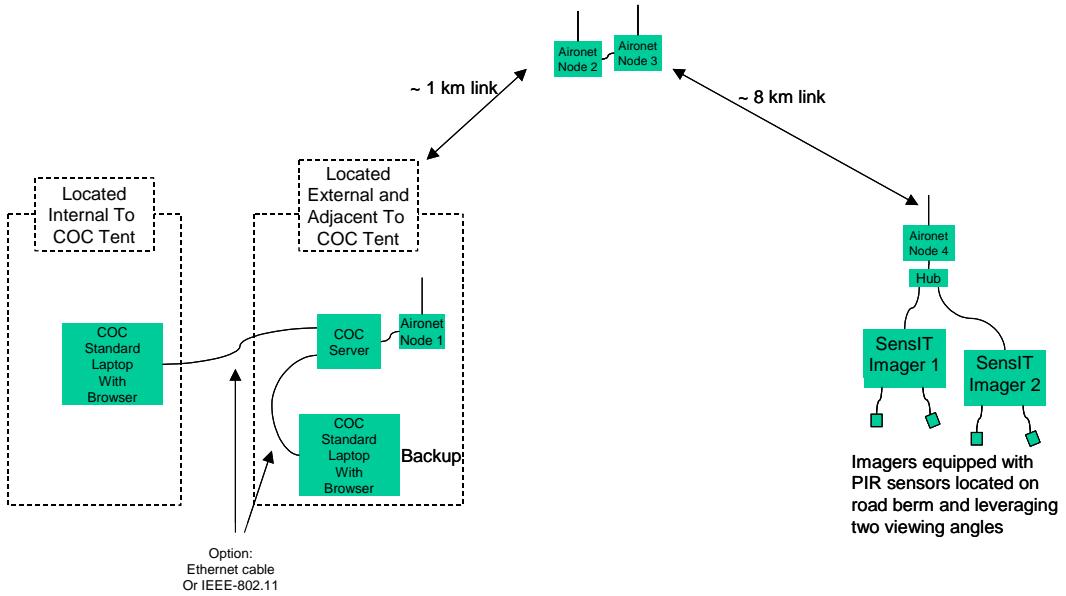


Figure 33. Steel Knight network architecture

#### 4.8.3.1 Imager Current Data Page

The WINS Imager 2.0 Current Data page shows the view of Figure 34. The user can click on an image to obtain a full size image and then scroll through any of the full size images. At each acquisition event, a snapshot of the data collected via two infrared sensors, an acoustic and a seismic sensor are shown, along with a sequence of five pictures snapped at 1s intervals around the acquisition trigger.

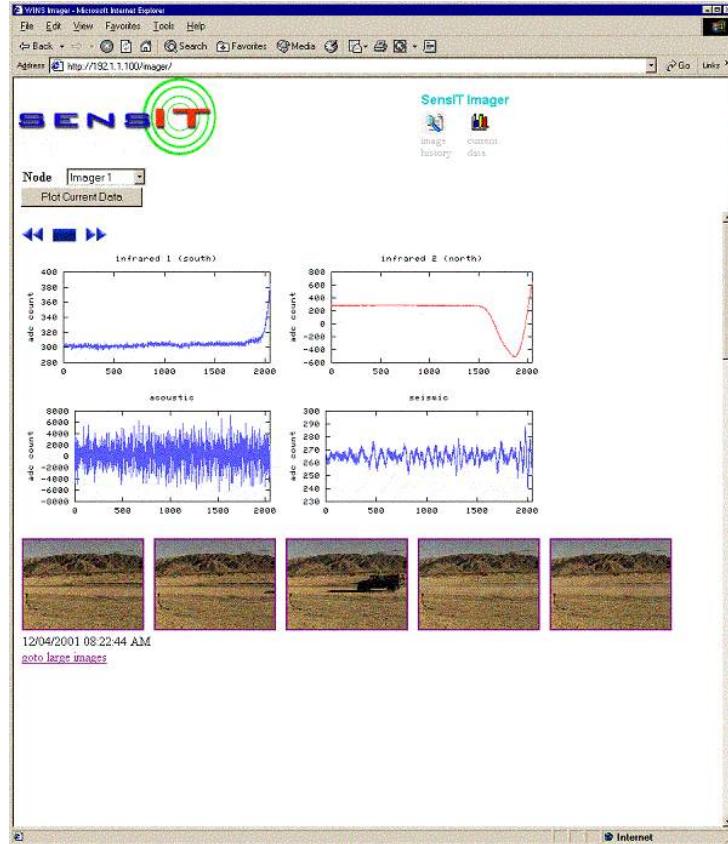


Figure 34. WINS Imager 2.0 Current Data Page.

Five images are shown in the browser view of Figure 34. The five images are captured in a time sequence, with each image separated by 1 second in time. Two images are acquired prior to the trigger event, one at the time of the trigger, and two images are acquired after the trigger event. To support this operation, each imager camera is constantly buffering images, although only those associated with an event are passed onto the web server.

#### 4.8.3.2 Image Triggering

Image triggering is derived from two passive infrared sensors. The imagers are trained to collect an angle of view crossing the road with both imagers located at the same separation from the road near a point on a berm adjacent to the road. Imager 1 is adjacent to Imager 2. For the Steel Knight setup, the Imager 1 and Imager 2 viewing angles differed by about 30 degrees. The angle bisecting their viewing angles is perpendicular to the road. The arrangement is shown in Figure 35.

The two passive IR sensors, sampling detection beams facing slightly northwesterly and southeasterly, detect north- and south-bound vehicles and personnel, respectively, and are used to trigger image transfer to the webserver. Either the north or south bound sensor will trigger an image. The data trace associated with the sensor that initiated a trigger will be shown in a red color. All others will be blue, as seen in Figure 34.

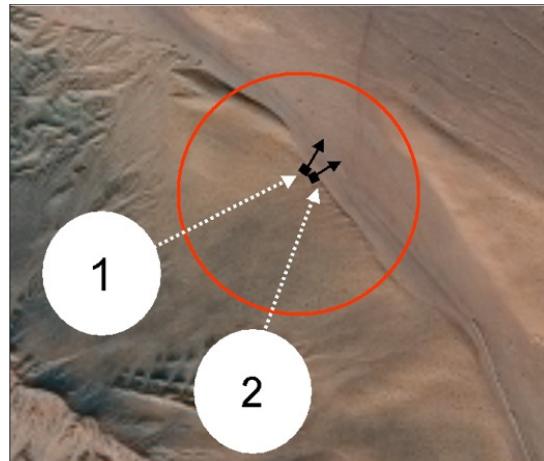


Figure 35. Imager 1 and 2 deployment at a berm near road. The Imager locations are indicated by the black rectangles and the Imager viewing angles are indicated by the arrows.

#### 4.8.3.3 Image History Page

The WINS Imager Image History page can be reached from any of the Imager web interface pages from the icon seen in the upper right corner of each web page. This page allows the user to enter a time and date range and launch a database query to recover the images acquired during these times. A sample of the Image History page is shown in Figure 36.

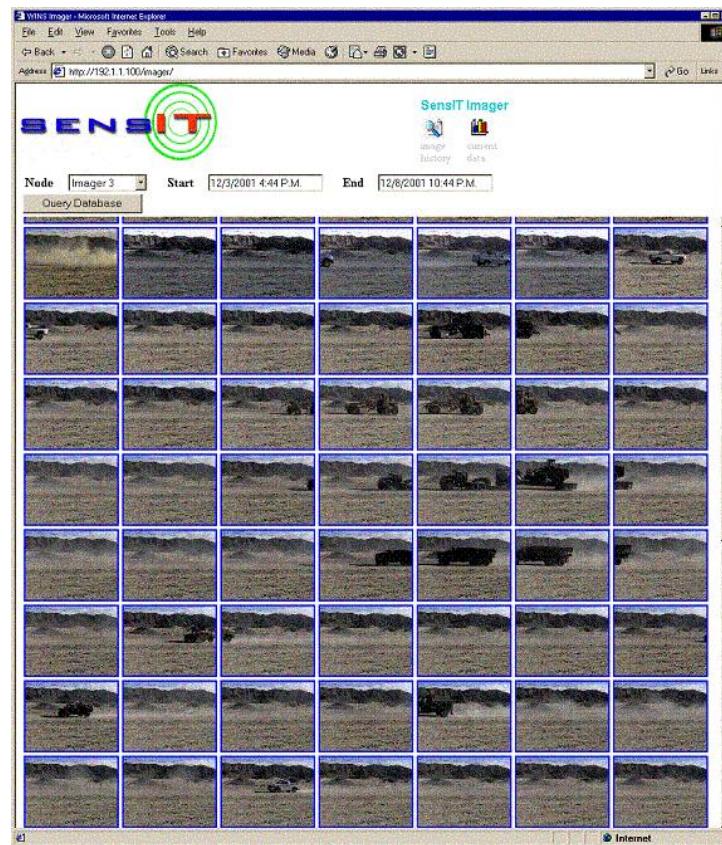


Figure 36. View of the WINS Imager 2.0 History Page.

#### 4.8.3.4 Alarm Window Page

An alarm function is constantly vigilant at the browser to enable an alarm indication for the user. This functionality produces a pop-up window that appears when either Imager 1 or Imager 2 detect an event. The alarm function is implemented as a Java applet and Java script and will operate without requirement for installation of software on the machine hosting the browser.

This alarm function allows the user to turn attention to other tasks and when an alarm occurs, the user is notified. The alarm pages, shown in Figure 37 and Figure 38, indicate the location and viewing angles of the imagers and the COC. Note that the system is setup to enable future improvements so that many imager locations may be triggered and viewed in this way, providing the user with immediate notification.

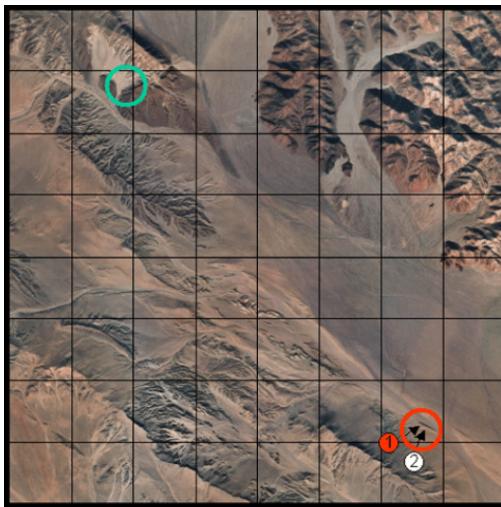


Figure 37. Alarm Page pop-up window graphic indicating alarm state for Imager 1.

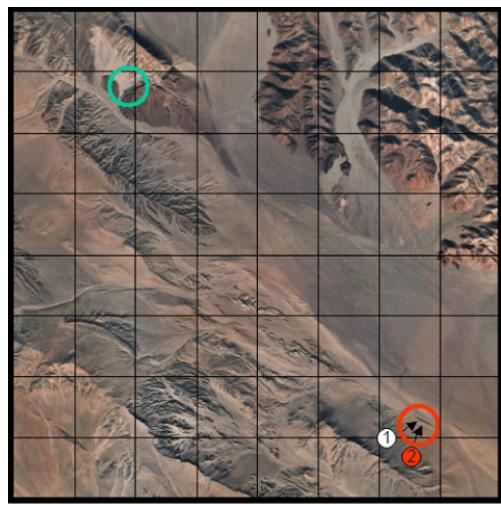


Figure 38. Alarm Page pop-up window graphic indicating alarm state for Imager 2.

#### 4.8.3.5 WINS Imager Deployment Images

To provide an idea of the deployment of the WINS Imager 2.0 system at Steel Knight, a view from the relay point (used to enable 802.11b access) down to the COC is shown in Figure 39, with the corresponding view from the relay point to the location of the imagers in Figure 40.

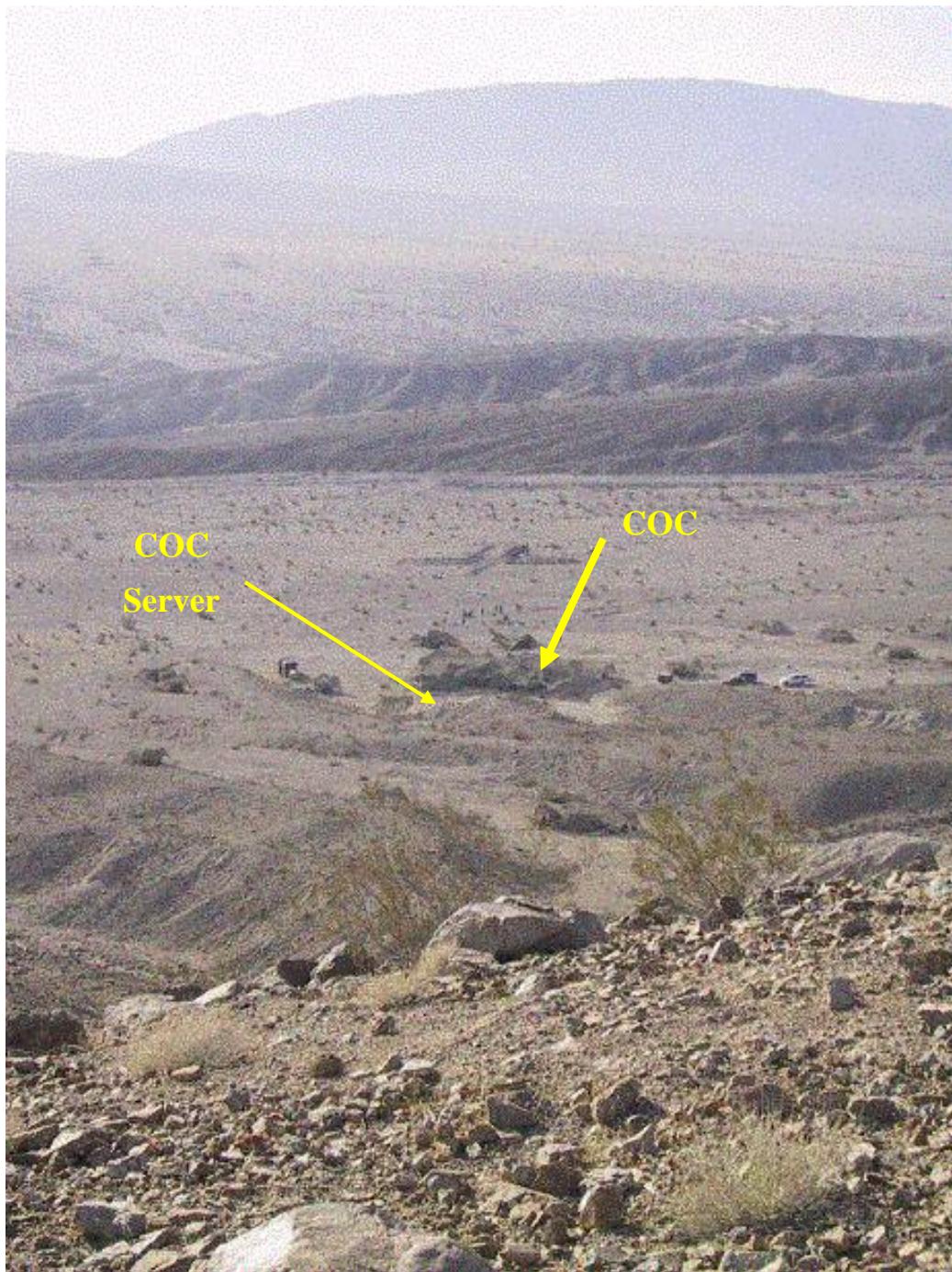


Figure 39. View of COC area from OP Kumar



Figure 40. View from OP Kumar towards Sensor Site. Dust from vehicle passage is observed on the roads.

#### 4.8.3.6 WINS Imager 2.0 Deployment at Steel Knight Overview

This section provides a survey of the images in the Steel Knight COC Server database. These were acquired during the Steel Knight exercise period.

The database of images collected at Steel Knight was browsed to select representative images. They were selected for images that in particular, show both interesting vehicles and events where the advantages of multiple image views, multiple image times, and multiple image angles provide tactical value. These images are shown below.

For example, Figure 41 through Figure 47 show the value of multiple angles and image backgrounds. Also, it is clear here that the image provides information on the weapons being carried by a vehicle.

Figure 48 through Figure 50 show the value of an image sequence, revealing details of a long vehicle and trailer.

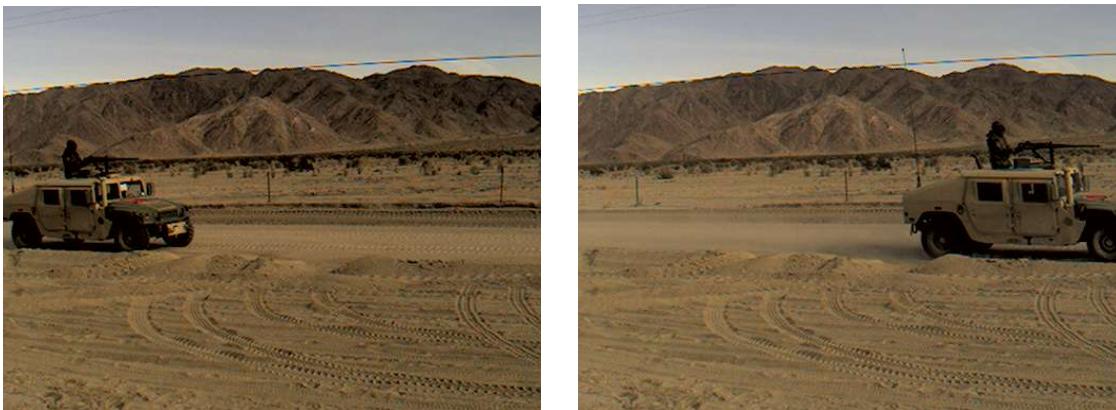


Figure 41. Imager 1 captures HMMWV with automatic weapon in time sequence image pair. Note that image sequence offers two viewing angles and backgrounds, rendering the weapon more visible in the second image.  
(From 6 Dec 2001 image database.)



Figure 42. Imager 2 captures HMMWV with automatic weapon (as shown in Figure 41). Note that this provides another set of angular views and backgrounds. (From 6 Dec 2001 image database.)



Figure 43. Imager 1 captures AAV. (From 6 Dec 2001 image database.)



Figure 44. Imager 2 captures AAV of Figure 43. (From 6 Dec 2001 image database.)



Figure 45. Imager 1 sequence showing HMMVW with automatic weapon. (From 6 Dec 2001 image database.)



Figure 46. Imager 2 sequence showing HMMVW with automatic weapon. (From 6 Dec 2001 image database.)



Figure 47. Imager 2 and Imager 1 capture an LAV passage at 13:31 on 5 Dec.



Figure 48. M925 5-Ton in first of an Imager 1 sequence. (From 6 Dec 2001 image database.)



Figure 49. M925 5-Ton in second of an Imager 1 sequence – note vehicle is towing howitzer.



Figure 50. M925 5-Ton in third of an Imager 1 sequence – note view of howitzer.

#### 4.9 Additional WINS NG 2.0 Deployments

The WINS Imager deployment at Steel Knight represented one of many deployments of the WINS NG 2.0 sensor systems during the SensIT program. In addition, more than 70 nodes were setup at the MCAGCC at 29 Palms for two weeks in November of 2001, both for data collection and to test software implementations and algorithms on the nodes. This test was an expanded version of that discussed in section 3.4. An illustration of the layout for 75 WINS NG 2.0 nodes at SITEX02 is shown in Figure 52, with a picture of an individual node deployed at SITEX02 shown in Figure 51.

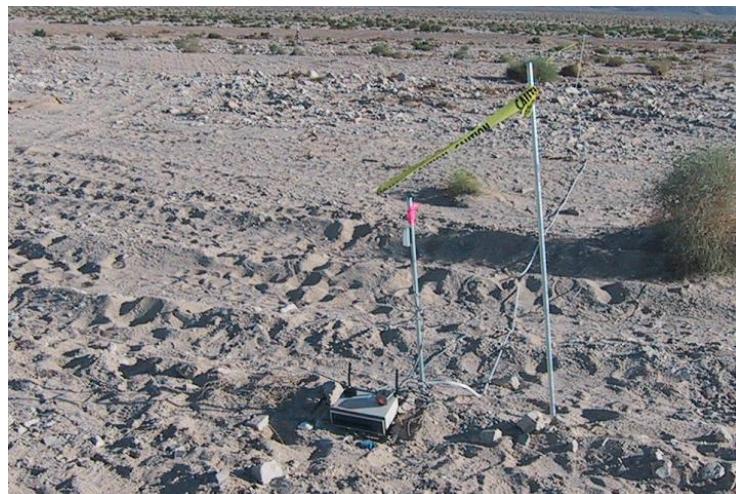


Figure 51. WINS NG 2.0 node deployed at SITEX02. The large pole with caution tape was used to mark the location of the node to prevent it being run over.

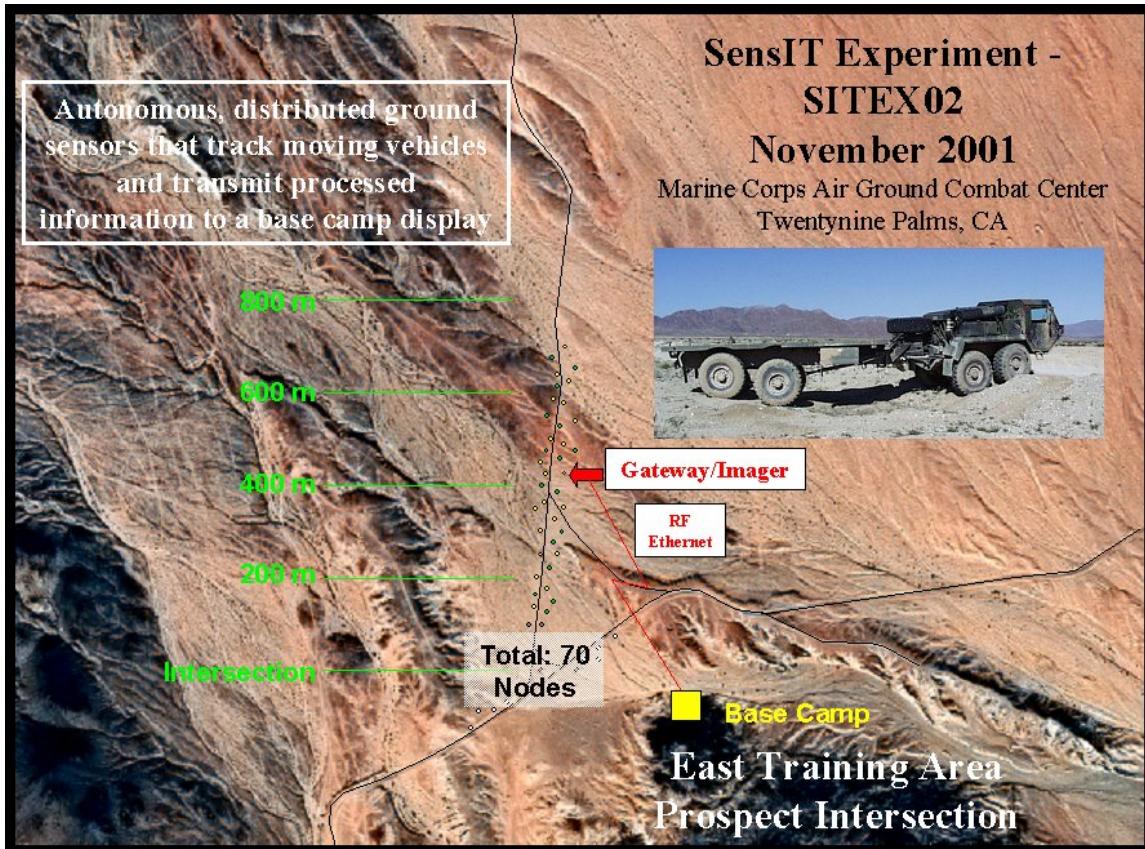


Figure 52. Node layout, aerial map, and overview of the SITEX02 Experiment using 70+ WINS NG 2.0 nodes.

In addition to deployment at SITEX02, the SensIT and NRL SRSS communities, to support their wireless sensor network research, used over 120 WINS NG 2.0 nodes. For example, to complete the SensIT program, three testbeds of WINS NG 2.0 nodes were setup at BBN's Cambridge facility, BAE's Austin facility, and PARC's Palo Alto facility. Concurrent demonstrations were presented via the internet at the final SensIT PI meeting. The flexibility and cross between an embedded physically constrained and development enabling wireless sensor network system of the WINS NG 2.0 system has been thoroughly demonstrated in these large sets of tests. In addition, significant feedback and further work by Sensoria Corporation, within the WINS NG program, has been used to contribute to the design of our next generation WINS NG 3.0 sensor system described in section 6.

## 5 Sensoria Networking for NRL SRSS

In addition to the support of the SensIT community within the WINS NG program, Sensoria Corporation has also supplied WINS NG 2.0 nodes and design improvements on those nodes to support the NRL SRSS program. This support has included the delivery of three WINS NG 2.0 development nodes and integrated software suite to NRL, support of these delivered nodes, an in progress investigation of the current capabilities of Ultrawideband (UWB) radio suppliers including the maturity of their solutions and feasibility for integration into WINS systems, and development of a prototype radio driver for IP connectivity via an arbitrary wireless interface. Further detail on the prototype radio driver investigation is provided below.

## 5.1 Initial Prototype for IP Connectivity over Arbitrary Wireless Interfaces

The initial architecture for the universal IP capable driver effort has been developed for use of arbitrary radio systems within WINS NG nodes. A number of constraints and requirements have been taken into account in driving the design process. These include:

- Use user space processes as building blocks of the overall driver architecture as much as possible. This will allow minimal amounts of modification to the Linux kernel initially on the WINS NG 2.0 and 3.0 nodes.
- The driver is comprised of two distinct portions: the upper section, that will be hardware independent, and the lower section, that is specific to the type of radio modem used.
- The driver architecture will provide a control and management interface similar to that of “ifconfig”. (The wireless modem will appear as another “network” interface to the system.)

The initial approach for connecting the IP stack inside a Linux based environment is to yank/inject IP frames from/to the kernel. These IP frames are effectively complete IP packets that have been formed by the stack inside the kernel. The frames are then brought up to the user space by means of the tun/tap kernel modules.

A user space process(es) then provides an “RF adaptation” layer. This RF adaptation layer performs the following tasks:

- Direct the packet to the correct local radio interface.
- Perform packet segmentation and reassembly.
- Retrieve over the air incoming packets and feed them to the kernel for processing by the stack.

The diagram of Figure 53 depicts this idea.

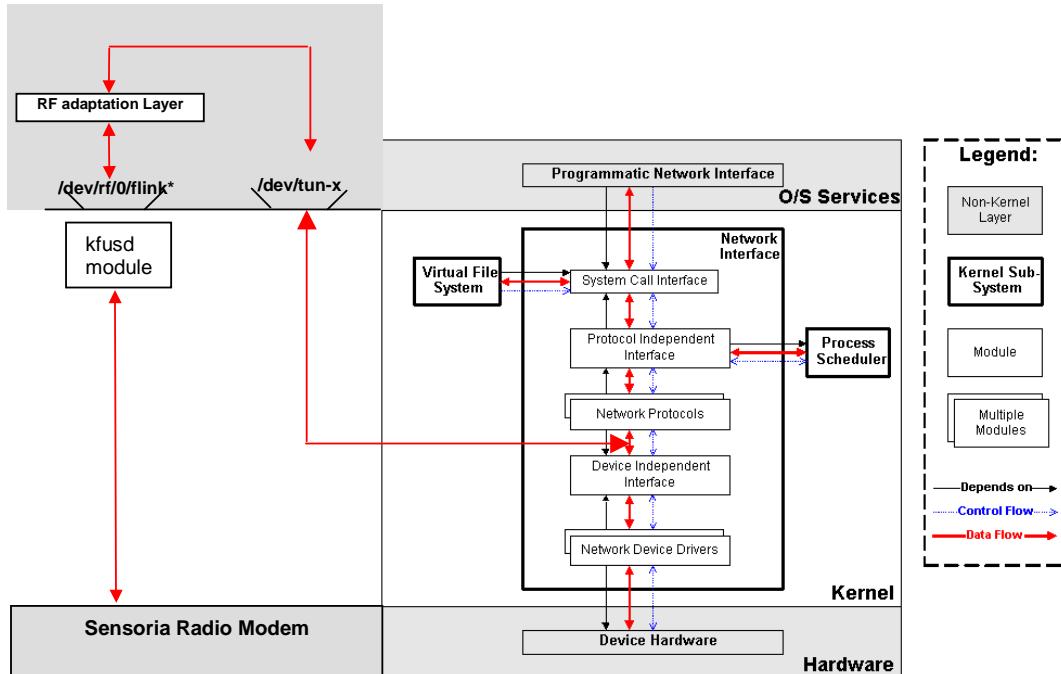


Figure 53. The layout of the preliminary driver architecture for universal wireless IP networking.

## 6 WINS NG 3.0 Research

The WINS 3.0 system is a next-generation modular embedded platform. It has been designed to meet the application requirements of a wide range of UGS applications, leveraging our experience with the WINS NG 1.0, 2.0, and prior systems. The 3.0 platform design supports very low-power operation and is fully modular. This platform consists of a number of modules, including those shown in the sample module stack in Figure 54.

In the system configuration shown in Figure 54, a processor module, equipped with a 400 MHz Intel PXA250 processor, 32 MB of flash memory, and 64 MB of SDRAM, is the main system processor. This module has a number of integrated interfaces, including serial ports and analog inputs and outputs. The expansion module provides further interface capabilities, including additional serial ports and an Ethernet port, an embedded GPS module, and the system power supply and battery charger.

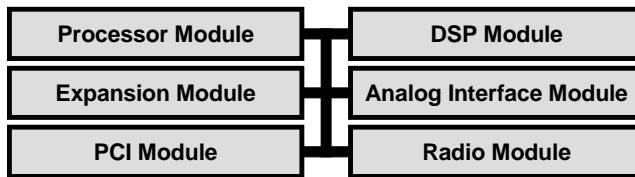


Figure 54. Example of a system module stack

Consistent with the Preprocessor in prior WINS platforms, the WINS 3.0 DSP module, based around a 160-MIPS TI DSP, is dedicated to handling all hard real-time tasks in the system, allowing the main system processor to operate unencumbered by harsh timing requirements. The DSP module is capable of processing data acquired through the analog interface and, acting as a system bus master, can transfer the data to the main system processor.

The platform is capable of supporting up to 16 independent analog input channels, each with a dedicated 24-bit ADC. The converters are preceded by variable-gain amplification and signal conditioning stages that are optimized for interfacing to geophones and microphones.

The system is radio agnostic, with interfaces for a variety of radio modules. With the radio interface module, radios with serial, PCI, and miniPCI interfaces can be supported, with dual radio module interfaces available for most interface types.

The PCI interface available on the PCI module allows easy expansion of the system with COTS components. CF and PCMCIA/CardBus slots are incorporated into the module for further addition of storage and interface resources to the system. Although PCI is not a low-power interface solution, it carries the advantage of being very common, allowing many functions to be added rapidly to systems using it as the interface. With the modular nature of the system, the PCI interface can be removed if not needed to reduce system power consumption.

Low-power system operation is ensured through the ability to independently control the power state of individual modules. Additionally, both of the processors used in the system support dynamic clock and core voltage scaling that allows processing capabilities to be matched to processing needs, reducing the power consumption of the system when it is not under heavy load.

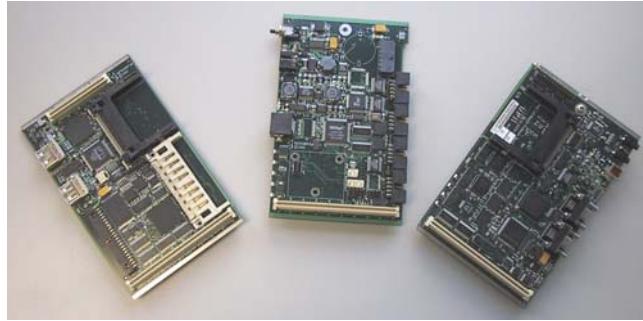


Figure 55. Sensoria next-generation WINS 3.0 embedded system modules.

Within the WINS 3.0 system, the comprehensive, open software framework based on the Linux 2.4 kernel developed for the WINS 2.0 nodes is under further refinement to provide a robust and powerful operating and development environment for custom applications. In addition, the current WINS 3.0 design represents a form factor reduction over both the 1.0 and 2.0 systems.

## 7 Concluding Remarks on the WINS NG Program

### 7.1 SensIT Program

The original projected goals for the SensIT program were to provide two versions of the WINS NG development system to the SensIT developers. Initially, these were planned as delivered in the first and third year of the program. Within the course of this effort, there was significant additional effort not originally projected, at the developers' request for additional capability and to move the delivery of the 2<sup>nd</sup> generation development system up by a year. In addition to the actual platforms supplied to the SensIT community, significant development work was performed to improve those systems and to support and enable the wider development community, as illustrated with the examples presented in the preceding sections. Overall, the support of the SensIT community with our WINS NG program has been very successful, leading to significant demand for the delivered WINS NG 2.0 nodes at the program completion.

### 7.2 NRL SRSS

The support of the Naval Research Laboratory SRSS program, through delivery of sensor nodes, development of a general WINS IP radio driver, and the survey of alternative Ultrawideband radio options for WINS systems, has also been very successful. Each of these accomplishments has been met, supporting the wider networking research being conducted at NRL.

### 7.3 List of Publications and Inventions Supported by the Contract

To date, the focus of the SensIT contract on providing a hardware platform to the community has not resulted in any technical journal publications. However, that development work has been described in technical conference papers partially developed within the SensIT program to date, including:

- 1) W. Merrill, K. Sohrabi, L. Girod, J. Elson, F. Newberg, and W. Kaiser, "Open Standard Development Platforms for Distributed Sensor Networks", AeroSense Conference, Orlando FL, April 5, 2002.

- 2) K. Sohrabi, W. Merrill, J. Elson, L. Girod, F. Newberg, and W. Kaiser, "Scaleable Self-Assembly for Ad Hoc Wireless Sensor Networks", Proceedings of the IEEE CAS Workshop on Wireless Communications and Networking, Pasadena, CA, Sept. 5, 2002.
- 3) William M. Merrill, Fredric Newberg, Kathy Sohrabi, William Kaiser, and Greg Pottie, "Collaborative Networking Requirements for Unattended Ground Sensor Systems", accepted to the 2003 IEEE Aerospace Conference, March 8-15, 2003, Big Sky, MT.
- 4) F. Newberg, W. M. Merrill, D. McIntire, B. Schiffer, J. Elson, L. Girod, K. Sohrabi, and W. J. Kaiser, "Networked, Tactical Embedded Platforms for Unattended Ground Sensor (UGS) Applications", the 28th Annual GOMAC Tech Conference, March 31, 2003 to April 3, 2003, Tampa, Florida.
- 5) D. McIntire, W. M. Merrill, F. Newberg, K. Sohrabi, W. J. Kaiser, "Energy Aware Networked Embedded Systems for Tactical Unattended Ground Sensors", the Proceedings of SPIE, Unattended Ground Sensor Technologies and Applications V, AeroSense 2003, April 21-25, 2003, Orlando, FL.